Speech Characteristics of Professional Fighters

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SPEECH CHARACTERISTICS
OF
PROFESSIONAL FIGHTERS

by

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ABSTRACT

The aims of this project were to accurately measure and describe speech characteristics of professional fighters; and to analyze the future potential of using speech characteristics as biomarkers for acquired neurogenic decline or chronic traumatic encephalopathy (CTE). The Professional Fighters Brain Health Study (PFBHS) is a longitudinal project investigating the effect of repeated head trauma in professional combatants. The PFBHS provided recorded speech samples for this project. This study measured accurate speech characteristics of 102 professional boxers and mixed martial artists and compared these results to a group of 27 age-matched healthy controls. Analysis revealed a significant difference in articulation rate between fighters and controls. Additionally, fighters produced more frequent interruptions in the forward flow of speech such as pauses and disfluencies. Clinical implications of this project include a better understanding of the speech symptoms associated with acquired neurogenic decline, or CTE.

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INTRODUCTION

A growing body of research describes an increased risk of degenerative neurologic decline after a history of repeated head trauma with both concussive and subconcussive events (Banks et al., 2017). There are numerous populations at higher risk for sustaining multiple head trauma including military personnel, victims of domestic violence, and athletes. Because of the nature of their sports, professional boxers and mixed martial artists are especially susceptible to neurologic disorders associated with repeated head impacts. Speech, a highly complex behavior requiring precisely timed, rapid, and accurate movements involving dozens of muscles and many neurological systems, is remarkably sensitive to neurologic damage (Duffy, 2013). As part of a larger study dedicated to identifying speech and language biomarkers associated with repeated head impacts in fighters, the present study examines speech recordings from the Professional Fighters Brain Health Study (PFBHS).

The PFBHS is a long-term study examining the changes of brain anatomy and function for a cohort at high risk of sustaining repeated blows to the head (Bernick et al, 2013). Although the label chronic traumatic encephalopathy (CTE) has often been used to describe the neurodegenerative syndrome associated with boxing, the label is problematic. At present, agreement on clinical diagnostic criteria is lacking; the neuropathology of the disorder is not well understood, and the amount of exposure required – whether repeated injuries are required or if a single head injury can cause later onset neurodegeneration – has not been resolved (Smith et al., 2019). In this paper, we will discuss motor speech deficits associated with repeated head impacts (RHI) in fighters. For clarity, we will use the term CTE when it has been employed by authors in cited literature.

Clinical features associated with RHI in boxing

Martland (1928) was the first physician to formally describe the clinical features associated with the “Punch Drunk” syndrome in boxers, observing symptoms such as parkinsonian gait, vertigo, tremor, and mental deterioration. Gavett, Stern, and McKee (2011) defined CTE as a “neurodegenerative disease that occurs later in the lives of some individuals with a history of repeated head trauma.” They stated that in athletes, the average age of CTE onset is eight years after retirement, and that the course is especially protracted in boxers. Bernick and Banks (2013) summarized the findings of many decades of studies on boxers. Behavioral changes such as paranoia, aggression, and irritability are relatively early symptoms of neurologic dysfunction in boxers. Cognitive dysfunction tends to occur later in the progression of symptoms, and motor features including gait disturbance, parkinsonism, and dysarthria are also observed in later stages. There is also growing concern regarding the effect of RHI in mixed martial arts (MMA) fighters because victory in a bout is often dependent on “concussing an opponent into a defenseless position through blunt head trauma” (Lim et al., 2019). Head injuries are the most common type of injury sustained by MMA participants, with 90% of knock-outs resulting from repetitive head strikes (Lim et al., 2019). This focus on head injury, in addition to the risk of oxygen deprivation, likens the sport of MMA to boxing, and promotes the idea that MMA fighters face similar risks of progressive neurologic decline as professional boxers (Lim et al., 2019).

Motor speech features in boxers

Motor speech features have often been reported in the literature for RHI in boxers. In the boxers he examined, Martland (1928) noted that some had “hesitancy of speech” and the “facial characteristics of the parkinsonian syndrome.” Parker (1934) reported a case of a 30-

year-old boxer with nasality and “indistinct,” slow speech, a sucking reflex, and “spasmodic laughter” similar to that observed in pseudobulbar palsy. He also reported on a 28-year-old boxer whose speech was “thick, muffled, and hard to understand” with a “rasping, labored quality of voice.” This boxer also exhibited abnormal jaw and sucking reflexes suggesting damage to the frontal lobes of the cerebrum. Of the 11 boxers described by Critchley (1957), six of them presented with motor speech symptoms. One boxer whose symptoms were described as “reminiscent of a Frontal-lobe tumour” had “extreme slowness” of movement and “some dysarthria.” A second had “thick” speech. Critchley’s Case 3 had “a nasal type of dysarthria” with an expressionless face and tendency to dribble. Cases 9 and 11 were labeled as “Cerebellar” types of disorder: one had “slight” dysarthria and the other had “marked” dysarthria with a “mask-like face.” Case 10, labeled as the “Striato-cerebellar type” had “altered” articulation with “staccato” dysarthric speech. Spillane (1962) described two boxers with speech symptoms as part of their disorders. One had slurred speech consisting “solely in defective articulation” who had to speak slowly and carefully in order to be understood. The second man exhibited progressive slowing of speech in which “two pints of beer would often render it incomprehensible.”

Later reports of boxers with neurologic disorders in the medical literature generally provide little description of speech issues beyond “dysarthria” or “slurred speech” (e.g., Taylor, 1953; Mawdsley & Ferguson, 1963; Payne, 1968; Mendez, 1995; McCrory et al., 2007). However, two recent reports of boxers with neurologic disorder exist in the speech pathology literature. McMicken, Ostergren, and Vento-Wilson (2011) described the speech of a 36-year-old boxer with ataxic dysarthria attributed to repeated blows of the head. He presented with slurred speech that sounded “inebriated” – a frequent descriptor for ataxic dysarthria associated with disorders of the cerebellar control circuit (Duffy, 2013). Oral mechanism examination revealed no deficits in range, symmetry, or strength of orofacial movements. Vowel prolongation was within normal limits (20 s), but diadochokinetic rates for repeated syllables were slow (3 per second). His speech intelligibility was rated as 3.7 on a scale of 1 (no errors) to 7 (unintelligible), and perceived severity was rated 3 to 4 on a scale from 0 (normal) to 4 (severely deviant). His intelligibility and severity ratings improved after completing loud speech treatment.

Berisha et al. (2017) examined recordings of speech produced over many years by boxer Muhammad Ali, who was diagnosed with Parkinson disease in 1984. Anecdotal reports of Ali's speech in the late 1970s and early 1980s noted slurring and slowness. Berisha et al. found that from 1968 to 1981, Ali's speech rate declined by 26% from over 4 syllables per second to 3 syllables per second. His vowel space area, a measure of articulatory precision, declined significantly in later years while pitch range and intensity range (measures of prosodic integrity) did not change with time. However, pitch and intensity range were correlated with the length of time post-fight: periods of monopitch and monoloudness occurred immediately after fights but resolved with time.

Boxing and MMA can result in damage to a variety of neurological structures many of which are associated with speech motor control. Clinically, boxers have exhibited cerebellar, extrapyramidal (associated with parkinsonism), and pyramidal (cerebral) dysfunction in varying combinations (Casson & Viano, 2019). Corsellis (1973) described the neuropathologies he observed in the brains of 15 former boxers including abnormalities of the septum pellucidum (the partition between the lateral ventricles), scarring to the inferior surfaces of the lateral lobes of the cerebellum, depigmentation of the substantia nigra (which supplies neurotransmitters to the basal ganglia), and neurofibrillary tangles throughout the cerebrum and brainstem. Many retired boxers have exhibited cerebral atrophy in CT scans (Casson & Viano, 2019). Damage to areas of the involved in speech motor control, including the pyramidal, extrapyramidal, and cerebellar circuits, can result in varying types of dysarthria, apraxia of speech, or neurogenic stuttering.

Motor speech disorders associated with RHI lesion sites

Several types of motor speech disorders are associated with head injury: dysarthria, neurogenic disfluency, and acquired apraxia of speech. Dysarthria is a "collective name for a group of neurologic speech disorders that reflect abnormalities in the strength, speed, range, steadiness, tone, or accuracy of movements required for the breathing, phonatory, resonatory, articulatory, or prosodic aspects of speech production" (Duffy, 2013, p. 17). These abnormalities can be categorized into seven distinct types of dysarthria, each type having a different underlying neuropathophysiology (Duffy, 2013). Unfortunately, the mention of dysarthria in the recent body of literature published about neurologic decline in fighters is often vague to determine the type of dysarthria and the underlying neuropathology. Considering the organic damage that has been reported on autopsy or in imaging studies (McKee et al., 2012; Handratta et al., 2010), clinical symptoms may be similar to those of other studied disorders that include corresponding neuropathologies. This includes damage to the basal nuclei resulting in Parkinson-like symptoms, cerebellar damage resulting in ataxic dysarthria, and damage to the cerebral hemispheres similar to patients with TBI and stroke, resulting in unilateral upper motor neuron dysarthria or spastic dysarthria.

Parkinsonian symptoms are prominent in clinical descriptions of the aftermath of RHI in fighters (Berisha et al., 2017; McKee et al., 2012; Forstl et al., 2010). Parkinsonism is associated with dysfunction of the basal ganglia circuitry and an imbalance between the direct and indirect pathways of movement that originate there. Clinical symptoms include "festinating" or shuffling gait, resting tremor, rigidity, loss of postural reflexes, and bradykinesia (slowness of movements). Speech characteristics associated with the hypokinetic dysarthria of Parkinson's disease include reduced pitch variability, and increased pause duration (Harel et al., 2004). The speech of patients in the later stages of the disease is marked by imprecise consonants, reduced volume, lack of stress changes, and a marked decrease in intelligibility (Tykalova, 2016). Speech rate abnormalities are common in PD: some individuals display reduced speech rate while others may appear to have overly rapid speech (Duffy, 2013). Speech disfluencies have also been noted in speakers with PD (Duffy, 2013; Goberman, Blomgren, & Metzger, 2010).

Damage to the cerebellum can result in ataxic dysarthria as a result of the rotational injury often sustained by boxers (Mendez, 1995; Forstl et al., 2010). The neuromuscular deficits associated with ataxic dysarthria associated with cerebellar insult include inaccurate direction of intended movement, irregular rhythm, slow rate of movement in the articulators, and reduced muscle tone (Duffy, 2013). The speech of people with ataxic dysarthria is marked by imprecise articulation, , excess and equal stress, monoloudness, monopitch, prolonged syllables, momentary irregular articulatory breakdowns, irregular intrasyllable voice fundamental frequency, and a breathy, weak, or unstable voice (McMicken et al., 2011). Reduced rate of speech and atypical pausing are also associated with cerebellar injury.

Damage from fighting can also affect one or both cerebral hemispheres. Cerebral damage can cause unilateral upper motor neuron dysarthria or spastic dysarthria, both of which are associated with reduced speech rate, ranging from mildly to severely slowed. Unilateral upper motor neuron (UUMN) dysarthria results from a unilateral lesion of the cortex, most often associated with a stroke, but can also result from an asymmetrical blow to the head (Duffy, 2013). Clinical presentation of UUMN dysarthria includes imprecise consonant production resulting from unilateral weakness of speech articulators, harsh quality of voice indicating paresis or paralysis of one of the vocal folds, and hypernasality depending on the degree of weakness affecting the muscles of the velum (Duffy, 2013). Spastic dysarthria results from bilateral damage to upper motor neurons in both the pyramidal and extrapyramidal tracts (Duffy, 2013). Spastic dysarthria is marked by reduced range and speed of motion of the speech articulators, reduced force, and excessive tone of the muscles involved in speech production. The clinical presentation of spastic dysarthria includes symptoms such as imprecise production of consonants, distortion of vowels, hypernasality, a strained or strangled voice quality, and reduced variability of suprasegmental speech (Duffy, 2013).

Individual subtypes of dysarthria often cooccur which results in a diagnosis of mixed dysarthria. According to Duffy (2013), mixed dysarthria is more common than any individual subtype. McKee et al. (2013) reported that individuals with neuropathology consistent with CTE often exhibited symptoms consistent with motor neuron disease which often presents with mixed dysarthria. Patients with a TBI diagnosis often have symptoms of mixed dysarthria because brain damage often includes “diffuse multifocal lesions” resulting from “rotational acceleration/deceleration causing axonal shearing and interruption of the interconnections among brain components" (Wang et al., 2004). Examination of the speech characteristics of patients with TBI diagnosed with mixed dysarthria revealed that they had reduced intelligibility, decreased syllable rate, abnormal voicing patterns, and increased pause duration between syllables (Wang et al., 2004).

In addition to dysarthria, brain trauma attributable to repeated concussive events can also result in acquired neurogenic stuttering. The symptoms of acquired neurogenic stuttering may present comorbidly with those of dysarthria, or they may be the only evidence of a speech abnormality (Duffy, 2013). Patients with TBI sometimes develop acquired neurogenic fluency disorders which manifest as stuttering-like disfluencies during speech (Lundgren, Helms-Estabrook, & Klein, 2010; Jokel et al., 2007). Penttila & Korpijaakko-Huuhka (2014) found that the most common disfluency after a TBI was part-word repetition, but other types of disfluencies were also present including blocks, prolongations, atypical or overly long pauses, distracting sounds, and interjections. People with Parkinson's disease also often exhibit stuttering-like disfluencies including within-word disfluencies (prolongations, and part-word repetitions) and between-word disfluencies (repetitions and revisions of whole words and phrases) (Goberman et al., 2010). The basal ganglia, the internal brain structure that has been definitively linked with Parkinson's disease, has also been implicated in neurogenic stuttering (Tani & Sakai, 2011; Alm, 2004). Other potential pathologies that can result in acquired neurogenic stuttering include seizure disorders, dementia, and stroke (Lundgren et al., 2010). All of these disorders can be linked with neurologic decline resulting from repeated head trauma.

Apraxia of speech is a motor speech disorder that can result from damage or degeneration of the motor speech programmer; a collection of cortical and subcortical structures involved in the planning and monitoring of speech production. It is reasonable to assume that apraxia of speech may be found in people who have suffered repeated head trauma because damage to the structures associated with apraxia is often found for boxers and mixed martial artists (Lim et al, 2019).Generally, the major structures of the motor speech planner are found in the left cerebral hemisphere; specifically, in the fronto-parietal region and related subcortical tract (Duffy, 2013). Clinical speech symptoms of apraxia include imprecise consonant production, slowed rate of speech, false articulatory starts and restarts, and effortful (visible and audible) trial and error groping for correct articulatory production (Duffy, 2013). Apraxia of speech may be associated with reductions of speech rate, increased pausing, and disfluent speech.

Description and focus of this project

Diagnosis of neurogenic decline and other disorders resulting from repeated head trauma remains controversial. There is neither consensus about anatomical presentations nor clinical symptoms. In order to make progress in understanding these disorders, it is necessary to describe their clinical presentations accurately and specifically. Despite robust research that delineates speech characteristics for neurogenic diseases listed above, a knowledge gap persists for labeling specific speech characteristics for people at risk for neurogenic decline associated with fighting. This study provides a detailed description of several speech characteristics – rate of articulation as well as

the number and duration of pauses and disfluencies - in professional boxers and mixed martial artists involved in the PFBHS in comparison to a control group. Articulation rate, number and duration of pauses in the forward flow of speech, and number and duration of disfluencies were chosen for this analysis because they can be measured reliably in read speech in audio files that were recorded in less-than-optimal conditions. In addition, changes in articulation rate, pausing, and fluency are associated with extrapyramidal, pyramidal, and cerebellar dysfunction previously documented in professional fighters.

The research questions addressed in this study are:

1. Are there differences in speech characteristics between professional fighters and age-matched healthy controls?
2. Are there differences in speech characteristics between two different types of professional fighters (boxers and mixed martial artists) as well as age-matched healthy controls?
3. Is there a correlation between speech characteristics and number of professional fights for professional fighters? Is there a correlation between speech characteristics and age for professional fighters? Is there a correlation between speech characteristics and level of education for professional fighters?
4. Are the speech characteristics of fighters with speech symptoms different from fighters without speech symptoms, and how do both of these groups compare to controls.

PARTICIPANTS AND PROCEDURES

Participants

Participants in this study were drawn from the Professional Fighters Brain Health Study (PFBHS), a longitudinal study of professional fighters that was instituted in 2011 to better understand the long-term effects of exposure to repeated head injury (Bernick et al., 2013). PFBHS participants include active and retired boxers and mixed martial arts fighters. The study was approved by the Cleveland Clinic Institutional Review Board, and all participants gave informed consent. Each participant received a battery of tests including neurologic exams, imaging tests, behavioral questionnaires, cognitive assessments, and blood samples at the Cleveland Clinic's Lou Ruvo Center for Brain Health in Las Vegas, NV. Many of the participants underwent the battery on multiple visits over several years (Bernick et al., 2013).

Audio recordings of the Rainbow Passage read aloud for 132 participants were supplied to the Speech Acoustics and Intelligibility Laboratory at the University of New Mexico under an agreement with the PFBHS. The participants were de-identified, with information including visit number, age, number of professional fights, primary language, country of birth, number of years of education, and presence of speech symptoms (as noted by the neurologist) supplied for each fighter.

In order to avoid the potentially confounding effects of second language acquisition on speech production, 103 participants whose primary language was English (62 boxers and 41 MMA fighters) were selected for this project. Of those 103, only 1 was female and was subsequently removed to maintain a more homogeneous cohort of 102 fighter participants. All selected participants were 18 or older and had completed at least 10 years of school. For this study, we used recordings from the earliest visit in which they read the passage aloud. Demographic information for each participant and summary data for age, number of fights, and years of education are shown in Table 1. Complete demographic information about every participant can be found in Appendix A.

	Fighters (N=102)			Controls (N=27)
	Years of Education	Number of Fights	Age	Age
Mean	13.35	23	39.39	42.22
SD	2.59	24	10.45	16.30
Minimum	10	0	24	20
Maximum	32	85	69	78
Range	22	85	45	58

Table 1: Description of participants selected for this project including years in school, age, and number of fights where available.

Control participants were 27 adult males drawn from a previous project on tongue strength and speech rate (Neel and Palmer, 2012). All members of the control group spoke English as their primary language and had no history of speech and language deficits. Mean age and age range was similar for fighters (mean = 39.4 years, SD = 10.5, range = 24 - 69) and controls (mean = 42.2, SD = 16.3, range = 20 – 78). Level of education data was not collected for the control participants in the original study, but all participants read the passage aloud without difficulty. Ages descriptions for control participant are shown in Table 1. Complete information about every control participant can be found in Appendix B.

Stimuli

Each participant read aloud the initial part of the Rainbow Passage, (Appendix A; Fairbanks, 1960, p. 124). Fighters were recorded in an examination room at the Cleveland Clinic Lou Ruvo Center for Brain Health in Las Vegas, NV with varying microphones and recorders. Controls were recorded in a sound treated room in the Department of Speech and

Hearing Sciences at the University of New Mexico using a Marantz PMD 670 digital tape recorder through a Shure SM-10a head-mounted microphone positioned about 1 cm from the corner of the speaker's mouth. Audio recordings for all participants were saved as .wav files.

Transcriptions for each recording were created using CHILDES CHAT/CLAN (CHILDES CLAN V8, 2019) software, indicating words, pauses, and disfluent productions. CHAT/CLAN software allows for simultaneous listening and transcribing of sound and video files. Three researchers including the author, one additional graduate student, and one undergraduate student in the Speech and Hearing Sciences program at the University of New Mexico worked on the CHAT/CLAN transcriptions. The author created a document with step by step directions (including screen-grab pictures) that the other two researchers followed when transcribing the reading samples. Figure 1 shows a sample CHAT/CLAN transcript output.

Figure 1: Example of CHAT/CLAN transcript.

Text grids for each recording were created in the acoustic analysis package Praat (Boersma & Weenink, 2020). The CHAT/CLAN transcripts were then opened in Praat. Following training by the thesis advisor and written instructions created by the author, four student researchers used the waveform and spectrogram displays along with the acoustic signal to mark each syllable, pause, and disfluent speech event from the CHAT/CLAN transcript in the text grid. Student researchers were trained by the author and thesis advisor using standard written definitions for each event (see below). Figure 2 shows a sample Praat output. A custom Praat script written by Mietta Lennes found at https://lennes.github.io/spect/ (SpeCT V 1.0.0, 2017) was used to measure the duration of each syllable, pause, and disfluency. All duration values were extracted into a Microsoft Excel (Microsoft Corporation, 2019) spreadsheet for analysis.

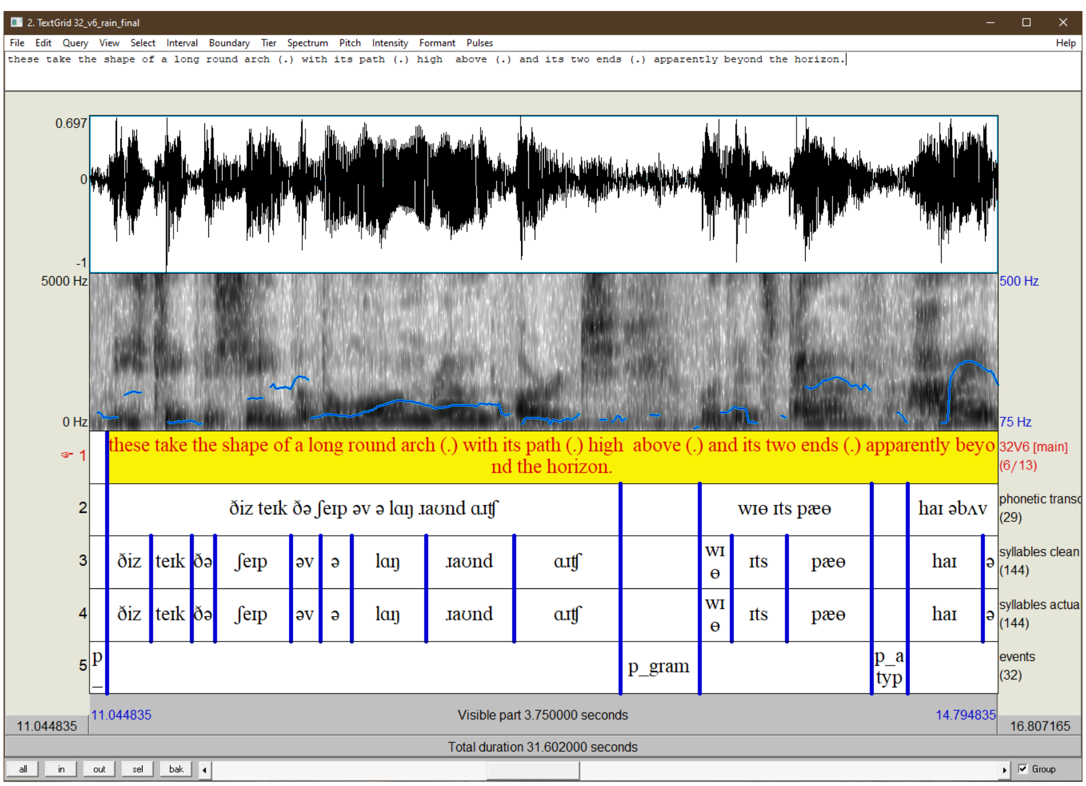

Figure 2: Example of Praat analysis.

Acoustic measures

The number and duration of syllables, grammatical pauses, atypical pauses, stuttering-like disfluencies, and other disfluencies were measured in each Rainbow Passage recording. Syllables are the units of speech organization consisting of a vocalic nucleus which can be preceded or followed by consonants. When possible, syllables began with a consonant (or consonant cluster) and ended with a vowel. For example, “division” consisted of three syllables: /dɪ/, /vɪ/, and /ʒən/. Post-vocalic consonant clusters were assigned to the end of a syllable, so that “apparently” was divided into the syllables /ə/, /pæ/, /ɹɛnt/, and /li/. Average syllable duration was calculated by averaging the duration of all fluently produced syllables. Articulation rate, defined as the number of syllables produced per second, was calculated by adding the duration of all fluently produced syllables and dividing by the total time it took in seconds to produce those syllables. Thus, articulation rate includes only the time taken to articulate the fluent syllables and does not include time taken by pauses, disfluencies, or other events.

Pauses were silences in the recordings that lasted for at least 100 ms and were not associated with articulatory behaviors such as voice onset time for pre-vocalic stop consonants or consonant closure intervals for post-vocalic stops (Robb, Maclagan, & Chen, 2004). Grammatical pauses (PGs) occurred at major or minor clause boundaries (Huber et al., 2012) and were marked for transcribers in a written copy of the passage. Grammatical pauses could occur at the end of each sentence and at syntactic junctures. In the complex sentence, “These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon,” grammatical pauses were marked between the words “arch” and “with” and between “above” and “and.” Grammatical pauses are often accompanied by the intake of a breath for production of the following sentence. Increased frequency of pausing for breath intake at has been documented in speakers with neurogenic speech disorders (Huber at al., 2012). There were 25 grammatical pauses (PGs) marked in the passage. Atypical pauses (PAs) occurred at non-grammatical locations in a sentence, such as within a prepositional phrase or between a noun and verb. Pauses at locations unrelated to syntactic boundaries are relatively unusual in healthy speakers but are known to occur in individuals with dysarthria (Huber et al., 2012) and may affect comprehensibility of speech for listeners (Hammen & Yorkston, 1994).

Disfluencies are defined as interruptions in the forward flow of speech other than silent pauses. Following Yairi and Ambrose (1992), two types of disfluencies were measured in this study: stuttering-like disfluencies (SLDs) and other disfluencies (ODs). Stuttering-like disfluencies are associated with developmental and neurogenic stuttering but occur relatively infrequently in typical talkers. They include part-word repetitions (e.g., “ruh ruh rainbow”), prolongations (e.g., “sssss-say”), and dysrhythmic phonations. Other disfluencies are observed in the speech of typical talkers and include interjections (such as “um” and “you know”), revisions (“the rainbow was/the rainbow is”), and phrase repetitions (e.g., “division of white light, division of white light into many…”). Each interruption in the forward flow of speech was marked as an “event” in a separate Praat tier. Each event was evaluated by either the thesis advisor or the author and were specifically labeled according to the abbreviations listed in Table 2. The author then combined the different marked events following the system outlined by Yairi & Ambrose (1992). Reading errors such as wrong words, phrases, or extra words were marked as events, but were not included in any of the disfluency categories, or in the calculation of articulation rate.

Filled pause	&-
Phrase revision	[//]_phrase
Word revision	[//]_word
Wrong word read (uncorrected)	word_sub
Wrong phrase read (uncorrected)	phrase_sub
Extra word (not in transcript)	Extra
Part word repetition disfluency	[^]_part
Interjection disfluency	[^]_int
Prolongation disfluency	[^]_prol
Phrase repetition	[/]_phrase
Word repetition	[/]_word
Interruptions (people/noise)	inter_
Pause (grammatical)	p_maj
Pause (atypical)	p_atyp

Table 2: List of abbreviations used to mark events in Praat

Reliability

Intra-rater and inter-rater reliability was measured for syllable durations, occurrence and duration of events. There were 20 randomly selected audio files transcribed from scratch with CHAT/CLAN, then those transcripts were exported into Praat, and every tier was marked for syllables and events. The author and another graduate student each completed repeated analysis of these 20 randomly selected participants. The author then ran the Praat script to extract the time data for the syllable durations and events of each participant. Intra-rater reliability was calculated by comparing those times against the time data obtained in the original analysis in SPSS to calculate the Pearson r correlation coefficient. Side by side comparison of Praat tiers was then conducted in order to ensure that the same events were marked during the reliability round of analysis. The author set the total number of events per speech sample at 100% and calculated the number of times that the first rater and the second rater had the same events marked. This number of concurrences over the total number of events yielded the percent agreement per sample.

Statistical analyses

All statistical analyses were conducted using IBM SPSS Statistics V25 (IBM Corportation, 2017). Pearson *r* correlation coefficient was used to calculate inter-rater and intra- rater reliability because the data was collected from work performed independently. The explore function in SPSS was used to generate descriptive statistics for each group and each variable. In order to assess normality of data, Kolmogorov-Smirnov and the Shapiro-Wilk tests were used in conjunction with values of skewness, kurtosis. Visualizations such as histograms, Q-Q plots and P-P plots were generated as well in order to evaluate if data were normally distributed. Homogeneity of variance was assessed with Levene's test whenever parametric tests were selected for analysis. Independent t-test analysis was used to compare two populations for variables that were normally distributed. ANOVA was used to compare three populations for variables that were normally distributed, and non-parametric tests were used to compare populations for those variables that did not have a normal distribution. The Mann-Whitney U-test was selected to compare two populations and the Kruskal-Wallis test was selected to compare three populations. Effect size was estimated with Cohen's *d* where *d* $= \frac{\text{Mean}_1 - \text{Mean}_2}{\text{SD}_1^2 + \text{SD}_2^2)/2}$; Cohen's *d* was used to calculate effect size for independent t-test analysis. Pearson *r* calculated with $r = \frac{z}{\sqrt{N}}$, where z is the standard test statistic and N is the sample size; effect size was estimated with r for Mann-Whitney U-test and for Kruskal-Wallis tests. The ω^2 was calculated with the formula $\omega^2 = \frac{\text{SSM} - (\text{dfM})\text{MSR}}{\text{SST} + \text{MSR}}$ where df_M is degrees of freedom, MS_R is the mean square between groups, SS_M is the between-group effect, and SS_T is the total amount of variance in the data; effect size was estimated with ω^2 for ANOVA tests. Correlational analysis was performed with Pearson *r* when both variables were normally distributed and Spearman rho when at least one of the variables was not normally distributed.

RESULTS

Reliability

Intra-rater and inter-rater reliability for syllable duration, and number and duration of pauses and disfluencies was calculated for 20 randomly selected participants out of the 129 (15.5%). Reliability for syllable durations and pause and disfluency durations was calculated using Pearson r correlation coefficient. Reliability for the frequency of pauses and disfluencies was calculated with a side by side comparison of marked events from first and second attempts for both inter-rater and intra-rater analysis. Percent agreement was calculated by setting the total number of events marked in the first attempt at 100% and marking differences in the frequency of pauses and durations in the second attempt. The summary for reliability measures is found in Table 3. Intra- and inter-rater Pearson correlation values for durations of syllables, pauses, and disfluencies were higher than .90, indicating sufficient reliability for acoustic measurements.

	Intra-rater	Inter-rater
Syllable duration	$r = .94; p < .00$	$r = .94; p < .01$
Frequency of pauses and disfluencies	Percent agreement = 98.3	Percent agreement = 91.8
Duration of pauses and disfluencies	$r = .97; p < .00$	$r = .90; p < .01$

Table 3. Intra-rater and inter-rater reliability summary.

Research question #1: Do fighters differ from controls in speech rate, syllable duration, number of pauses and disfluencies, and duration of pauses and disfluencies?

A summary of speech variables is presented in Table 4 for fighters and controls. The variables presented in the table are articulation rate (syl/s), syllable duration (ms), number of grammatical pauses (PG), number of atypical pauses (PA), number of stuttering-like disfluencies (SLD), number of other disfluencies (OD), duration of PG, duration of PA, duration of SLD, and duration of OD.

	Fighters (N=102)	Controls (N=27)
Articulation rate (syllables/s)	4.61 (.52) 3.23 – 6.04	5.23 (.70) 3.82 – 6.37
Syllable duration (ms)	220 (25) .17 - .31	195 (28) .16 - .26
Number of grammatical pauses (PG)	11.25 (3.49) 5 – 22	9.22 (2.52) 4 - 17
Number of atypical pauses (PA)	2.98 (4.59) 0 – 23	.93 (1.36) 0 - 5
Number of stuttering-like disfluencies (SLD)	.63 (1.17) 0 – 7	.15 (.36) 0 - 1
Number of other disfluencies (OD)	1.86 (1.88) 0 – 10	.63 (1.25) 0 - 5
Duration of grammatical pauses (PG) in ms	530 (160) 300 - 980	500 (110) .360 - 880
Duration of atypical pauses (PA) in ms	229 (50) 120 - 450	320 (140) 100 - 530
Duration of stuttering-like disfluencies (SLD) in ms	320 (560) 170 – 3090	670 (300) 230 - 900
Duration of other disfluencies (OD) in ms	860 (570) 60 – 2960	700 (290) 320 – 1050

Table 4: Summary of speech variables for fighters and controls. Data includes mean, (SD) and minimum-maximum range values for each variable.

Articulation Rate

Because articulation rate data was normally distributed, a parametric independent samples t-test was used to compare fighters and controls. Levene's test for equality of variances indicated that variances for fighters and controls were not equal ($F = 1.94$, $p < .02$), so the t-test results for equal variances not assumed was used. There was a significant difference between the two groups ($t = -4.30$, $p < .01$) as seen in Figure 3. As a group, fighters (mean articulation rate = 4.61syl/s, SD = .516) spoke 0.62 fewer syllables per second than controls (mean rate = 5.23syl/s, SD = .698). Cohen's *d* statistic of 1.01 indicated a large effect size (Cohen, 1988).

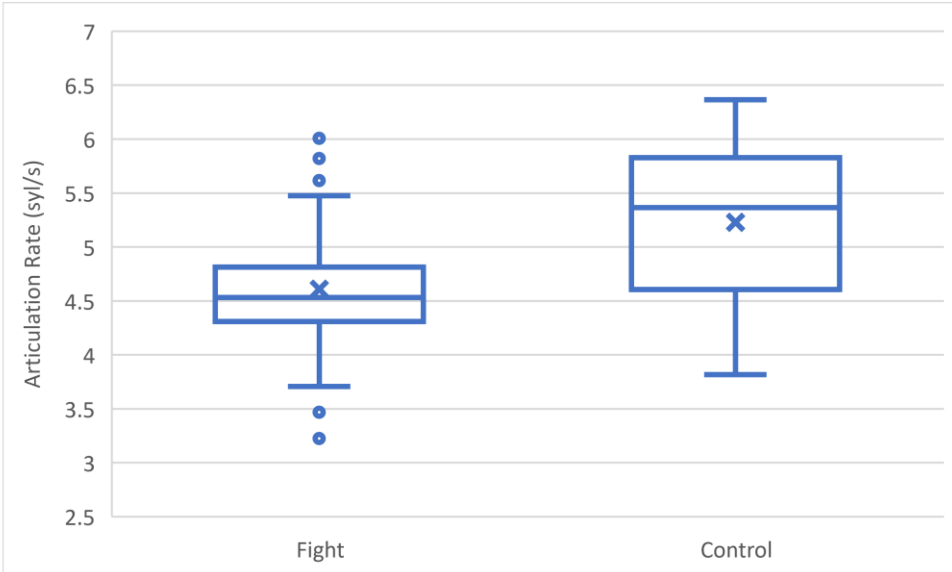

Figure 3. Box plot of articulation rate for fighters vs. controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Syllable duration

As with speech rate, syllable duration was normally distributed. Levene's test indicated that variances of the two groups were not equal, so the independent samples t-test results for equal variances not assumed was used. The t value of 4.57 ($p < .01$) showed that fighters had significantly longer syllable durations (mean syllable duration = 220 ms, SD = 24) than controls (mean = 195ms, SD = 28) as seen in Figure 4. Cohen's *d* statistic of .943 indicated a large effect size (Cohen, 1988). This finding is logical, given that articulation rate was based on syllable durations with pauses and disfluencies removed from the rate calculation.

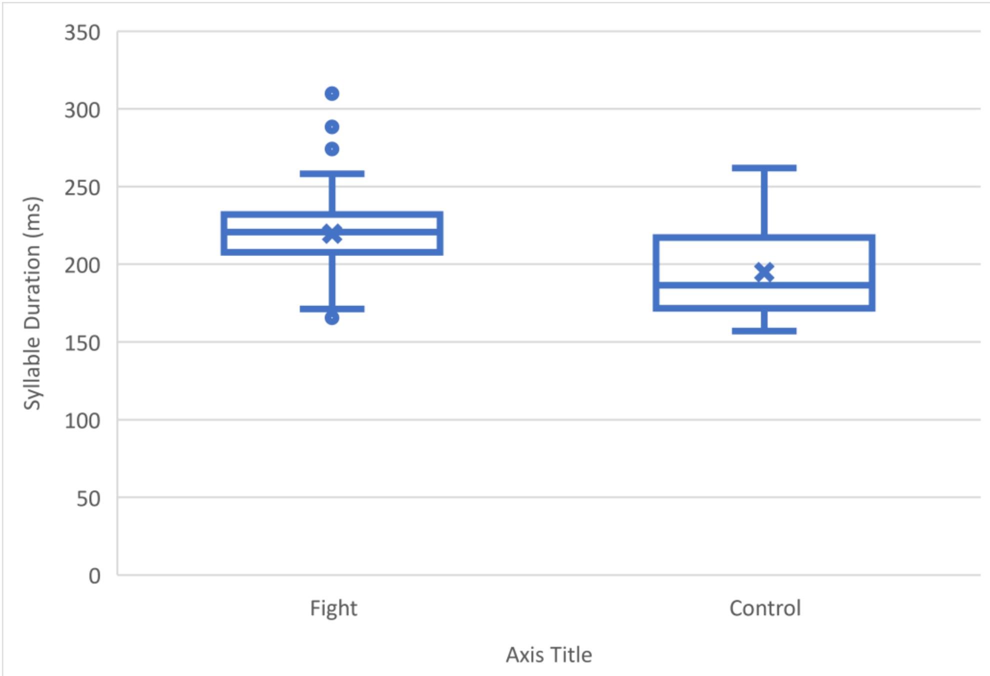

Figure 4 Syllable duration for fighters and controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Number of pauses and disfluencies

Although the number of grammatical pauses was normally distributed, and all participants had grammatical pauses, atypical pauses and both disfluency types were not normally distributed, and many participants did not demonstrate these behaviors. Therefore, non-parametric tests were used to compare the number of pauses and disfluencies for fighters and controls. The Mann-Whitney U test was selected for these comparisons because it does not require the assumptions of normal distribution and homogeneity of variances.

The Mann-Whitney U of 903.0 ($p < .01$) indicated a significant difference in the number of grammatical pauses between the fighters and control groups. Fighters (mean = 11.25, SD = 3.49) as a group had on average 2.03 more grammatical pauses than controls (mean = 9.22, SD = 2.52). Effect size was estimated by calculating *r*, (Field, 2018). The *r* value of .24 indicated a small to medium effect size (Cohen, 1988). Fighters also differed in number of atypical pauses from controls (U = 995.0, $p < .03$). As a group, fighters (mean = 2.98, SD = 4.586) produced 2.3 more atypical pauses per passage than controls (mean = .93, SD = 1.39), although the effect size was small (*r* = .20). 65 of the 102 fighters produced at least one atypical pause, and 12 out of the 27 control group members produced at least one pause of this type. Figure 3 includes box and whisker plots for a comparison of pause frequencies between fighters and controls.

Fighters produced significantly more stuttering-like disfluencies (SLDs) than controls (U = 1100.0, $p < .05$). The mean number of SLDs for the fighters' group was .63 (SD = 1.17) compared to a mean of .15 for the controls (SD = .362). The effect size was small (*r* = .18). However, only four control participants produced any SLDS, whereas 33 fighters had SLDs. Of the 33 fighters who had SLDs, 31 of them produced one to three SLDs. Only two fighters had more than three SLDs. Fighters also produced significantly more other types of disfluencies (ODs) than controls (U = 749.4, $p < .01$) with a medium effect size (*r* = .33). As a group, fighters (mean = 1.86, SD = 1.883) produced an average of 3.76 more ODs than controls (mean = .63, SD = 1.2). 73 fighters had at least one OD, whereas only 8 of the 27 controls produced this kind of disfluency. Figure 5 includes frequency comparison for SLDs and ODs.

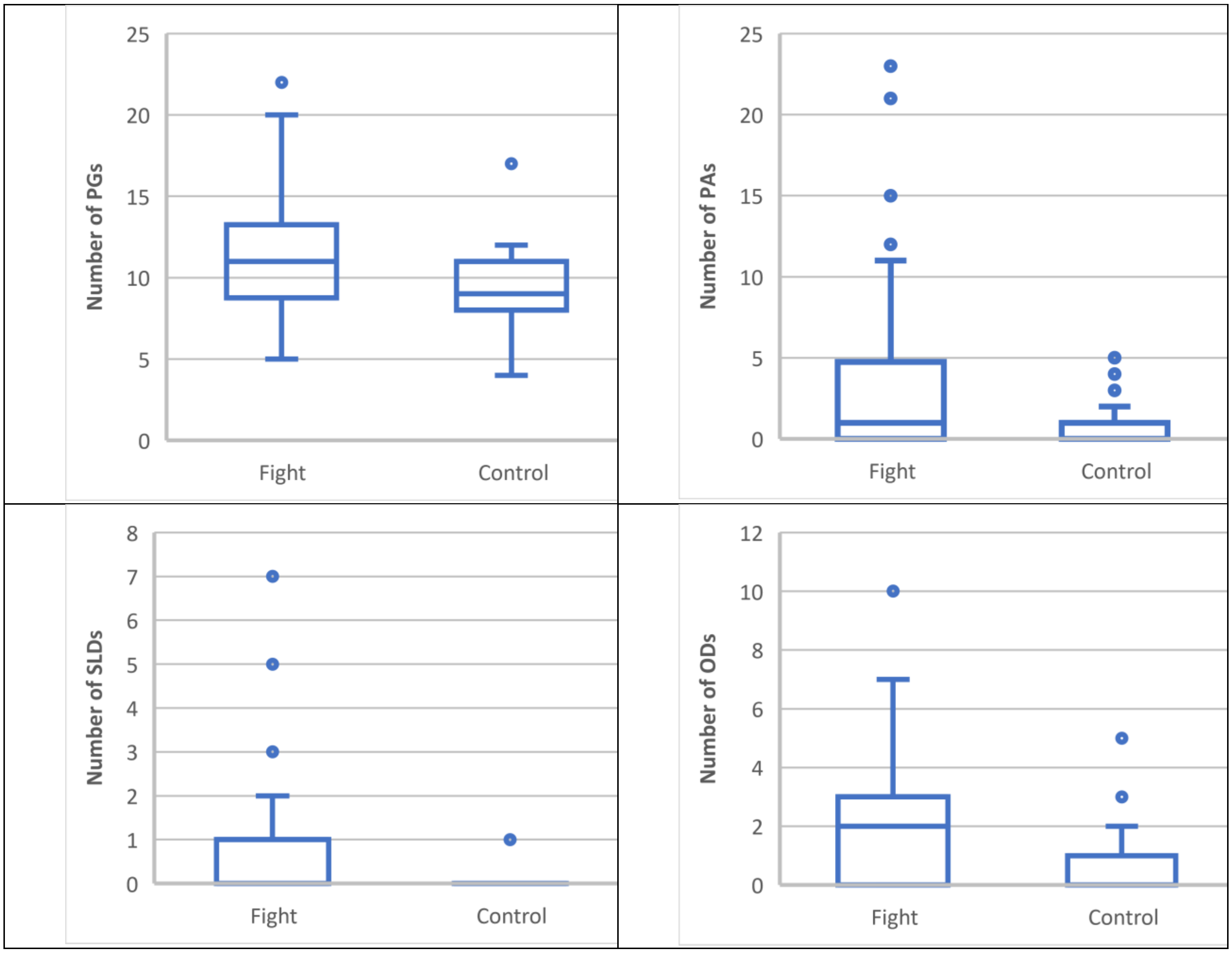

Figure 5: Box plots comparing fighters and controls for frequency of events. Number of grammatical pauses (PG) top left. Number of atypical pauses (PA) top right. Number of stuttering-like disfluencies (SLDs) bottom left. Number of other disfluencies (ODs) bottom right. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Duration of pauses and disfluencies

None of the variables for duration of grammatical pauses, atypical pauses, SLDs and ODs were normally distributed or passed the assumption for homogeneity of variance. Therefore, the non-parametric Mann-Whitney U-tests were used to compare the fighter and control groups. Figure 6 shows the graphical representation of duration variable data. No difference in duration of grammatical pauses between the two groups was found ($U = 1337.0$, $p = .82$). The mean grammatical pause duration for fighters was 527ms (SD = 16ms) and for controls was 500ms (SD = 11ms). Similarly, no difference in duration of atypical pauses was found between fighters and controls (U = 527.0, p=.054). As a group, mean atypical pause duration for fighters was 229ms (SD = 50ms) and for controls was 320ms (SD = 140ms). The atypical pause duration analysis contained cases from 65 fighters and 12 controls.

There were no significant differences between fighters and controls in the duration of SLDs (U = 77.0, p = .62) or ODs (U = 257.0, p = .58). For fighters, mean SLD duration was 621ms (SD = 560ms) and mean OD duration was 863ms (SD = 570ms). The mean SLD duration for controls was 670ms (SD = 300ms) and mean OD duration was 700ms (SD = 290ms). Relatively few participants contributed data to this analysis, as described in the section on number of disfluencies (33 fighters had SLDs and 73 had ODs; only four controls produced SLDs and eight had ODs).

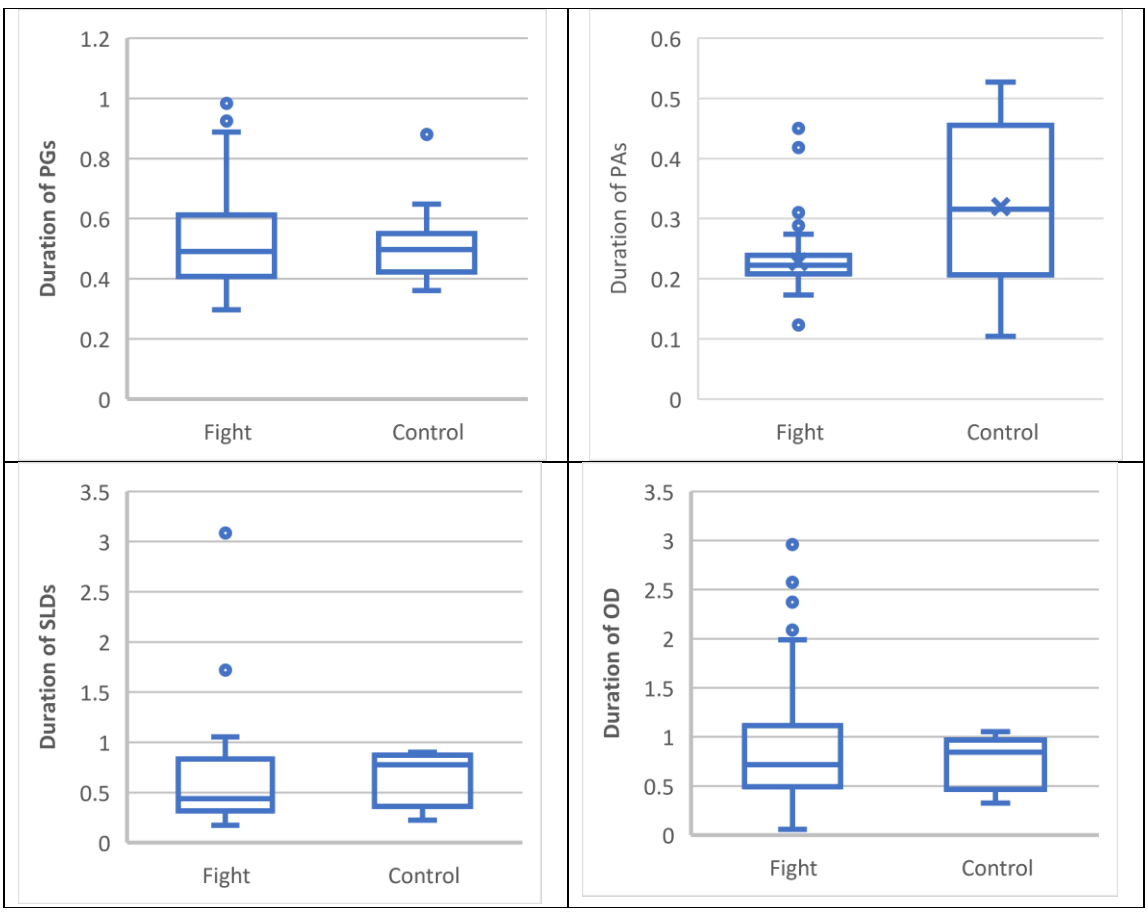

Figure 6: Box plots of event durations for fighters vs. controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Research question #2: Do different types of fighters (boxers, MMA) differ from controls and from each other in speech rate, syllable duration, number and duration of pauses, and number and duration of disfluencies?

Data for the boxers and MMA fighters separately as well as for controls is shown in Table 5.

	Boxers (N=62)	MMA (N=40)	Control (N=27)
Articulation rate (syllables/s)	4.59 (.50) 3.23 – 6.04	4.63 (.54) 3.87 – 6.01	5.23 (.70) 3.82 – 6.37
Syllable duration (ms)	220 (20) 170 - 310	219 (20) 170 - 260	195 (28) 160 - 260
Number of grammatical pauses (PG)	11.9 (3.76) 5 - 22	10.25 (2.78) 6 – 19	8.23 (2.52) 4 - 17
Number of atypical pauses (PA)	3.95 (5.43) 0 - 23	1.48 (2.10) 0 - 7	.93 (1.36) 0 - 5
Number of stuttering-like disfluencies (SLD)	.84 (1.38) 0 – 7	.30 (.61) 0 - 2	.15 (.36) 0 - 1
Number of other disfluencies (OD)	1.97 (2.1) 0 - 10	1.70 (1.54) 0 - 5	.63 (1.25) 0 - 5
Duration of grammatical pauses (PG) (s)	567 (170) 310 - 980	465 (110) 300 - 830	500 (110) 360 - 880
Duration of atypical pauses (PA) (s)	232 (50) 120 - 450	224 (20) 180 – 260	320 (140) 100 – 530
Duration of stuttering-like disfluencies (SLD) (s)	715 (620) 190 – 3090	369 (230) 170 - 960	670 (300) 230 – 900
Duration of other disfluencies (OD) (s)	940 (660) 60 – 2960	746 (380) 180 – 2090	700 (290) 320 – 1050

Table 5: Summary of speech variables for boxers, MMA fighters, and controls. Data includes mean (SD) and minimum -maximum range values for each variable.

Speech Rate and Syllable Durations

Because articulation rate, syllable duration, and frequency of grammatical pauses data were normally distributed, an ANOVA test comparing the three test groups (boxers, MMA, control) was performed for each variable. These tests were performed independently, therefore in order to control for Type 1 error, the acceptable significance threshold for p was lowered from $p < .05$ to $p < .01$. (Field, 2018).

For articulation rate, the ANOVA showed a significant difference among the three groups [$F(2, 126) = 13.06$; $p < .01$]. Levene's test (3.34, $p < .04$) indicated non-homogeneity of variance. Omega squared (ω^2) was calculated to estimate effect size. The ω^2 value of .16 indicated a large effect size (Field, 2018). Because Levene's test indicated non-homogeneity of variance, Games Howell multiple post hoc comparisons were conducted (Fields, 2018). The mean articulation rate for boxers was 4.59 syl/s (SD = .504), for MMA fighters it was 4.63 syl/s (SD = .539), and for controls was 5.23 syl/s (SD = .698). Boxers did not differ significantly from MMA fighters (mean difference = -.040, $p < .927$) but did differ significantly from controls (mean difference = -.633, $p < .000$). MMA fighters also differed from controls (mean difference = -.594, $p < .001$). Figure 7 illustrates that both boxers and MMA fighters produced fewer syllables per second than controls.

Similarly, ANOVA was used to analyze differences in syllable duration across the same groups as described for articulation rate. Homogeneity of variance was assumed for the syllable duration data (Levene's statistic = 1.18; $p < .312$). ANOVA for syllable duration indicated a significant difference among groups with $F(2, 126) = 10.4$ ($p < .00$) and a large estimated effect size ($\omega^2 = .12$). The mean syllable duration for boxers was 220ms (SD = 25ms), for MMA fighters it was 219ms (SD = 24ms), and for controls it was 195ms (SD = 28ms). Similar to articulation rate, post hoc testing revealed no significant difference between boxers and MMA fighters (mean difference = .002, $p <.932$), but a large difference in syllable duration between boxers and controls (mean difference = .026, $p <.001$) and between MMA fighters and controls (mean difference = .024, $p <.002$). The plot for mean syllable duration confirms that the syllables spoken by control participants were significantly shorter than that of boxers or MMA fighters (Figure 7).

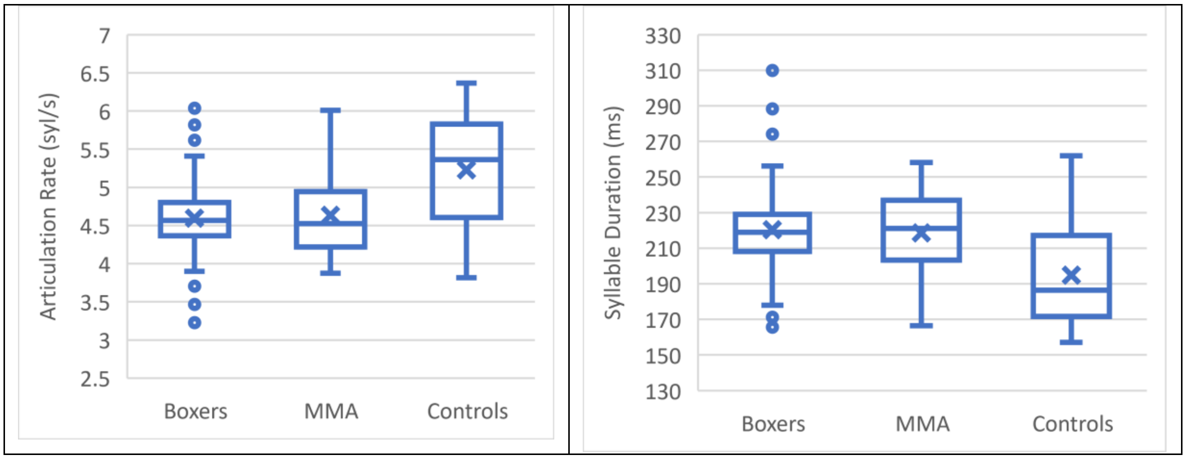

Figure 7: Box plots of articulation rate and syllable duration for the three test groups (boxers, MMA fighters, and controls). X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Number of pauses and disfluencies

All participants (62 boxers, 40 MMA fighters, and 27 controls) produced a number of grammatical pauses during their speech samples. ANOVA revealed a significant difference in the number of grammatical pauses among groups with F (2, 126) = 7.33 ($p < .001$) and a ω^2 of .09 indicating a medium to large estimated effect size. Levene's test revealed that data had heterogeneous variance, therefore the Games-Howell test was once again selected for post hoc comparisons. The mean number of PGs for boxers was 11.90 (SD = 3.76), for MMA fighters mean number of PGs = 10.25 (SD = 2.78), and for controls mean number of PGs = 9.22 (SD = 2.52). Post-hoc tests revealed that the difference in number of grammatical pauses between boxers and MMA fighters was not significant (mean difference = 1.653, $p < .033$). There was a significant difference in between boxers and controls (mean difference = 2.68, $p < .001$), but the difference between MMA fighters and controls was not significant (mean difference = 1.028, $p < .266$). Figure 6 shows frequency of grammatical pauses for all three groups, illustrating that the mean number of PGs for boxers is higher than the mean number of PGs for MMA fighters and controls. The data for frequency of atypical pauses, SLDs, and ODs was not normally distributed, therefore, the non-parametric Kruskal-Wallis test was used to assess differences among the test groups (Field, 2018). Pair-wise comparisons were conducted in order to discover which specific groups were significantly different, and in order to control the Type 1 error, acceptable significance level was set to $p < .01$.

The Kruskal-Wallis test revealed a significant difference in the number of atypical pauses across the groups [$H(2) = 11.27$; $p < .01$]. The mean number of atypical pauses for boxers was 3.95 (SD = 5.44). For MMA fighters, the mean number of atypical pauses was 1.48 (SD = 2.10). Controls had a mean of .93 atypical pauses (SD = 1.34). A pair-wise comparison revealed that boxers and MMA fighters did not have a significant difference in the number of atypical pauses ($H(2) = 17.76$; ($p < .05$). Boxers had significantly more atypical pauses than controls with $H(2) = 24.86$ ($p < .008$) with a medium effect size ($r = .32$). MMA fighters and controls did not differ significantly [$H(2) = 7.10$;$p < 1.00$]. Only 12 controls produced at least one atypical pause in the passage, whereas 44 boxers and 21 MMA fighters evidenced this type of pause.

The Kruskal-Wallis test did not show any significant findings in number of SLDs among the groups [$H(2) = 8.38$; $p < .02$]. The mean number of SLDs for boxers was .84 (SD = 1.38), for MMA fighters it was .30 (SD = .61), and for controls it was .15 (SD = .36). Pair-wise comparisons could not be performed because the result of the overall test was non-significant. Not all participants produced SLDs: only 24 boxers, 9 MMA fighters, and 4 controls had at least one SLD.

There was a significant difference in number of ODs among the test groups [$H(2) = 14.19$; $p < .01$]. Again, not all participants produced ODs in the passage: 43 boxers (mean number of OD = 1.97, SD = 2.08), 30 MMA fighters (mean = 1.70, SD = 1.54), and 9 controls (= .63, SD = 1.25) were included in this test. The pair-wise comparisons showed no significant difference between boxers and MMA fighters (H(2) = 1.402, p < .848). However, boxers had significantly more ODs than controls [H(2) = 29.94;p < .01] with a large effect size (*r* = .38). MMA fighters also had significantly more ODs than controls [H(2) = 28.54;p < .01] with a large effect size (*r* = .38). Figure 8 shows that the mean number of ODs for boxers and MMA fighters is larger than the mean number of ODs for controls.

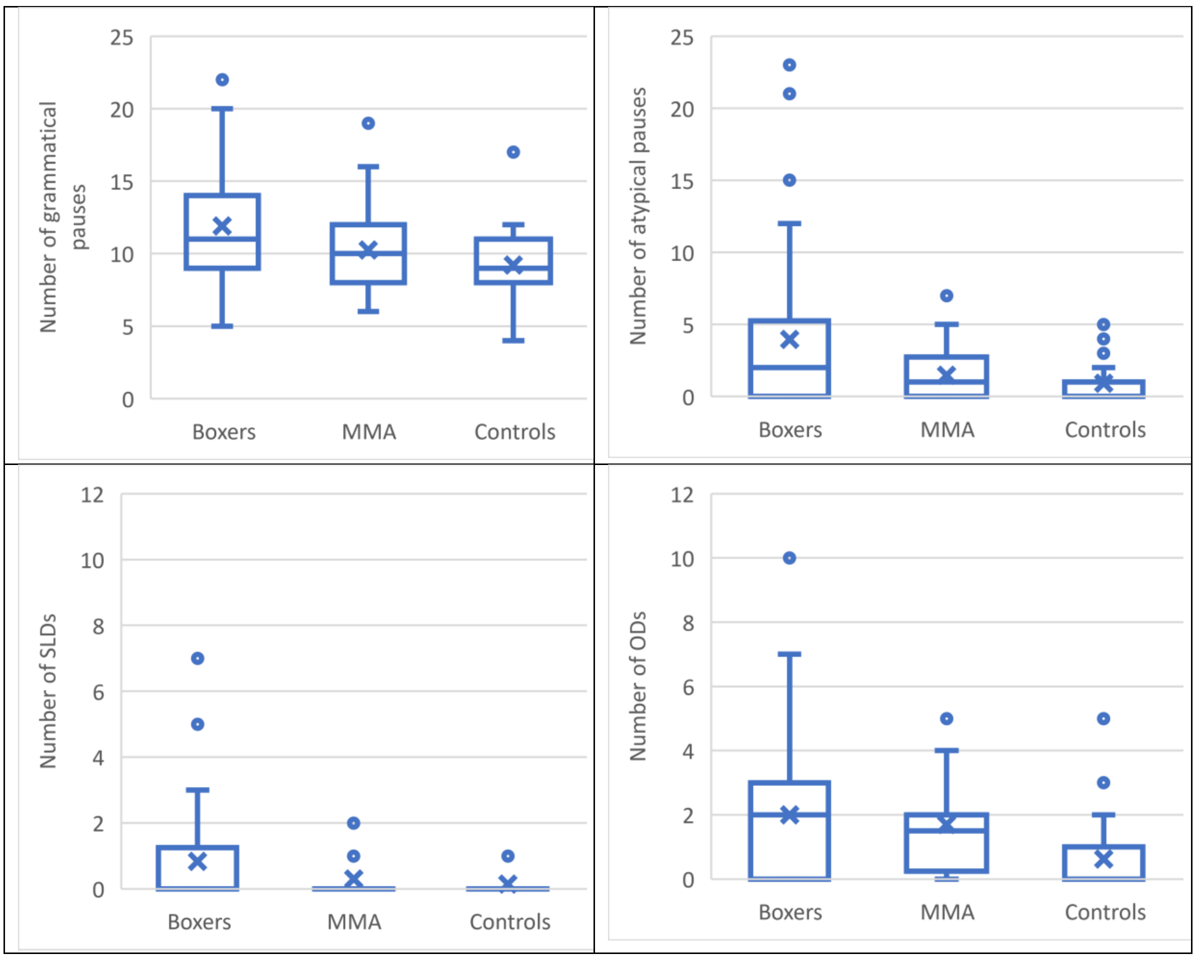

Figure 8: Box and whisker plots for frequency of events in the 3 test groups. Top left is frequency of PGs, top right is frequency of PAs, bottom left is frequency of SLDs, and bottom right is frequency of ODs. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Duration of pauses and disfluencies

None of the data for duration of pauses or disfluencies was normally distributed. Therefore, the Kruskal-Wallis test was used to compare these variables, with pair-wise comparisons to look for differences among the groups. The acceptable p-value was set at < .01 in order to limit Type 1 error resulting from running independent comparison tests. Sample size for duration of grammatical pauses included 62 boxers with mean PG duration of 567ms (SD = 170ms), 40 MMA fighters with mean PG duration of 465ms (SD = 11ms), and 27 controls with mean PG duration of 500ms (SD = 110ms). Results of the Kruskal-Wallis analysis found a significant difference in duration of PG [H(2) = 9.78;p < .01]. Pair-wise comparisons revealed that the contributing difference is between boxers and MMA fighters [H(2) = 23.63;p <. 01] and an estimated *r* of .31 indicating a large effect size. This means PGs for boxers lasted significantly longer than PGs for MMA fighters (Figure 9). The other two pair-wise comparisons were not significant: for boxers vs. controls, H(2) = 11.14 (p < .20), and for MMA fighters vs. controls, H(2) = -12.49 (p < .18).

Duration of atypical pauses included 44 boxers (mean duration = 227ms, SD = 50ms), 21 MMA fighters (mean = 224ms, SD = 20ms), and 12 controls (mean = 320ms, SD = 140ms). The results of the Kruskal-Wallis test indicated no significant difference in the duration of PA across the three test groups with H(2) = 4.44 (p < .11). Pair-wise comparison could not be performed because the overall test yielded no significant difference among groups. In Figure 9, it appears that the mean duration of PAs for controls is higher than the for the other two groups. However, there were very few control participants who had a PA, and the statistical analysis did not show a significant difference for this variable.

The sample sizes for the test groups were significantly lower for duration of SLDs with only 24 boxers (mean SLD duration = 715ms, SD = 620), 9 MMA fighters (mean SLD duration = 369ms, SD = 230ms), and 4 controls (mean SLD duration = 670ms, SD = 300ms). Analysis of duration of SLD data also yielded no significant differences with $H(2) = 6.68$ ($p < .04$). Pair-wise comparison could not be performed because the overall test yielded no significant findings.

Sample sizes for duration of ODs included more participants (43 boxers, 30 MMA fighters, and 8 controls). The mean duration of OD for boxers was 944ms (SD = 660ms), for MMA fighters it was 746ms (SD = 380ms), and for controls it was 700ms (SD = 290ms). Nevertheless, the Kruskal-Wallis test found no significant differences in duration among the three groups [$H(2) = 1.22; p < .54$].

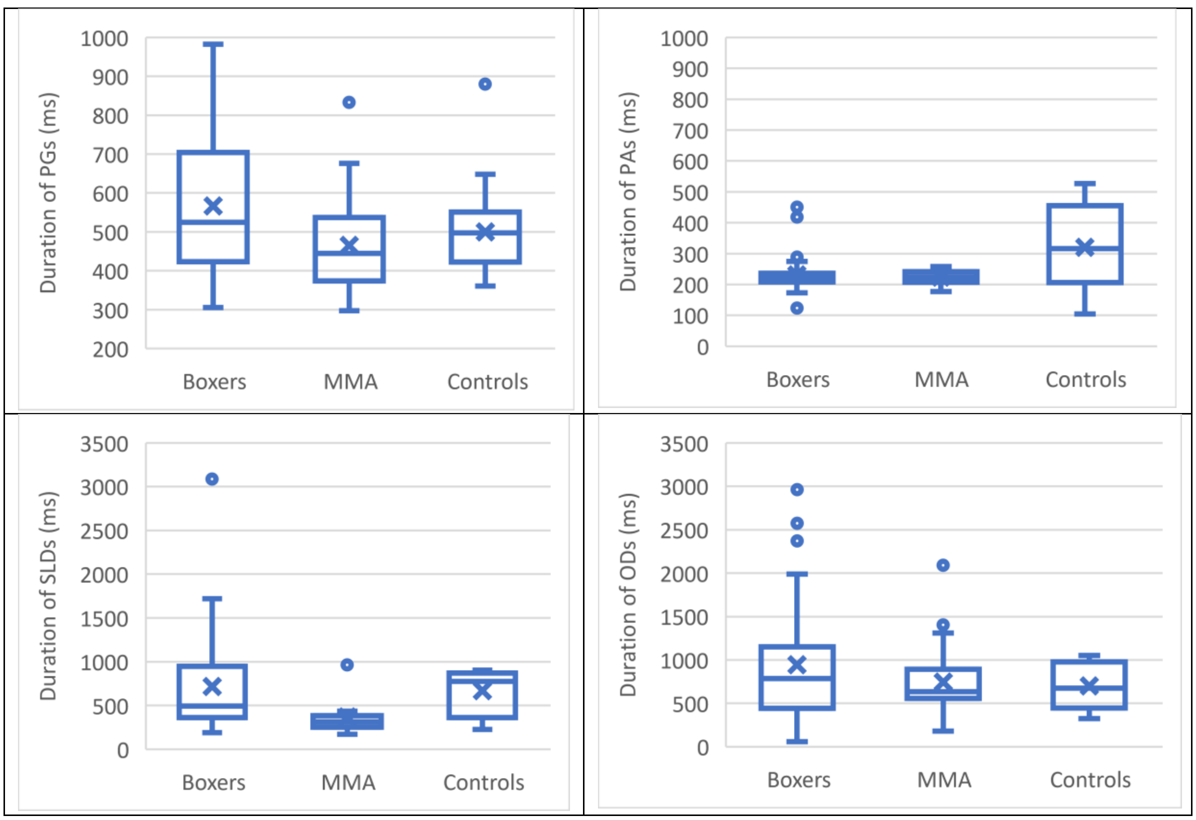

Figure 9: Graphs of duration of PG (top left), duration of PA (top right), duration of SLDs (bottom left), and duration of OD (bottom right). X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Research question 3: Is there any significant correlation in speech symptoms with number of fights, age, or years of education for fighters?

To explore any relations among age, fights, and level of education with the acoustic measures, a series of correlations was carried out. Age of fighters was normally distributed; therefore, Pearson r coefficient was used to correlate age with the other speech variables that were also normally distributed including articulation rate, syllable duration, and number of PG. For speech variables that were not normally distributed, the Spearman rho coefficient was used to evaluate any possible correlations with age. Table 6 summarizes the correlations of speech variables with age, number of fights, and years of education. Number of fights (NOF) and years of education (YOE) were not normally distributed, therefore Spearman rho coefficient was used to evaluate possible correlations between number of fights and speech variables as well as years of education and speech variables.

None of the acoustic measures were correlated with age. Not surprisingly, age was correlated with number of fights (r = .54, p < .01): older fighters tended to have experienced more bouts. Number of fights was also significantly correlated with number of grammatical pauses (r = .29, p < .01), number of atypical pauses (r = .21, p < .), and duration of SLDs (r = .22, p < 03.). These relatively weak correlations indicated that number of pauses and length of some disfluencies increased as the number of fights increased. Years of education was significantly negatively correlated with number of grammatical pauses (r = .24, p < 02) as well as number of ODs (r = -.22, p < .03) and duration of ODs (r = -.31, p < .01). Fighters with fewer years of education tended to produce more grammatical pauses and more and longer ODs.

Intercorrelation analysis revealed that articulation rate has a significant negative correlation with the number of atypical pauses (r = .31, p < .01), and the duration of grammatical (r = .30, p < .0) and atypical pauses (r = .92, p < .01). Other significant correlations were found in Table 6.

		# of Fights	Age	Years of Education	Articulation Rate	Syllable Duration	PGs	PAs	SLDs	ODs	duration of PGs	duration of PAs	duration of SLD	duration of OD
# of Fights	r													
	p													
Age	r	.54**												
	p	.01												
Years of Education	r	-.08	.01											
	p	.45	.96											
Articulation Rate	r	-.03	.03	.12										
	p	.77	.74	.24										
Syllable Duration	r	.03	-.04	-.12	-1.00**									
	p	.77	.73	.23	.00									
PGs	r	.29**	.15	-.24*	-.17	.17								
	p	.01	.13	.01	.09	.09								
PAs	r	.21*	.01	-.14	-.31**	.30**	.31**							
	p	.03	.92	.15	.01	.01	.01							
SLDs	r	.11	.07	.02	-.08	.08	.04	.44**						
	p	.27	.48	.85	.45	.45	.68	.01						
ODs	r	.07	-.11	-.22*	-.12	.12	.23*	.37**	.36**					
	p	.50	.29	.02	.22	.22	.02	.00	.01					
duration of PG	r	.17	.15	-.16	-.30**	.30**	.29**	.49**	.19	.22*				
	p	.09	.15	.11	.01	.01	.01	.01	.06	.03				
duration of PA	r	.07	-.02	-.04	-.92**	.92**	.27*	.37**	-.10	.08	.35**			
	p	.56	.85	.74	.01	.00	.03	.01	.45	.53	.01			
duration of SLD	r	.22	.11	-.15	-.02	.02	.39*	.43*	.10	.21	.49**	.07		
	p	.21	.54	.41	.91	.91	.02	.01	.58	.24	.01	.74		
duration of OD	r	.09	-.01	-.31**	-.28*	.28*	.20	.36**	.08	.17	.30*	.16	.34	
	p	.47	.98	.01	.02	.02	.09	.01	.52	.16	.01	.28	.09	

Table 6: Summary of correlation coefficients and p values. Pearson r was performed for only the correlation of age and articulation rate, age and syllable duration, and age and number of PG. The remaining correlations were calculated with Spearman rho. Significance at .05 level is marked with a *. Significance at .01 level is marked with a **.

Additional research question 4: Do fighters with speech symptoms noted by the neurologist differ from controls and fighters without documented speech symptoms?

	Fighters with speech symptoms (N=28))	Fighters without speech symptoms (N=74)	Controls (N=27)
Age	41.32 (9.67) 24 – 61	38.66 (10.71) 24 – 69	42.22 (16.30) 20 – 78
Number of Fights	32.07 (22.94) 0 -85	19.89 (18.69) 0 – 78	n/a
Years of Education	13.49 (1.90) 10 – 18	13.05 (1.72) 10 - 18	n/a
Articulation rate (syllables/s)	4.50 (.61) 3.23 – 5.82	4.65 (.47) 3.87 – 6.04	5.23 (.70) 3.82 – 6.37
Syllable duration (ms)	226 (31) 173 – 309	217 (20) 165 – 258	195 (28) 160 - 260
Number of grammatical pauses (PG)	11.68 (3.28) 7 - 19	11.09 (3.58) 5 – 22	8.23 (2.52) 4 - 17
Number of atypical pauses (PA)	4.46 (4.48) 0 – 15	2.42 (4.53) 0 – 23	.93 (1.36) 0 - 5
Number of stuttering-like disfluencies (SLD)	1.25 (1.76) 0 – 7	.39 (.74) 0 – 3	.15 (.36) 0 - 1
Number of other disfluencies (OD)	2.54 (1.99) 0 – 7	1.61 (1.79) 0 – 10	.63 (1.25) 0 - 5
Duration of grammatical pauses (PG) (ms)	600 (200) 310 - 980	500 (130) 300 - 890	500 (110) 360 – 880
Duration of atypical pauses (PA) (ms)	230 (30) 170 - 310	230 (50) 120 - 450	320 (140) 100 – 530
Duration of stuttering-like disfluencies (SLD) (ms)	630 (380) 290 – 1720	610 (670) 170 – 3090	670 (300) 230 – 900
Duration of other disfluencies (OD) (ms)	910 (710) 60 – 2960	840 (490) 120 – 2570	700 (290) 320 – 1050

Table 7. Summary of speech variables for fighters' group with speech symptoms and controls. Mean (SD) and minimum – maximum range values

In addition to information regarding age, number of fights, and level of education, the PFBHS identified a group of fighters who displayed speech symptoms such as slurred speech, dysarthria, or disfluency during at least one of the examinations conducted by a neurologist. The group with speech symptoms (WS) was comprised of 25 boxers and 3 MMA fighters To explore whether changes in speech rate, number and duration of pauses, and number and duration of disfluencies occurred for all fighters or more prevalent in those with perceived speech deficits, additional analyses were conducted.

Speech Rate

Articulation Rate

An ANOVA was performed to analyze differences in articulation rate between WS fighters, NS fighters and controls because the data was normally distributed. There were 28 WS fighters (mean articulation rate = 4.50syl/s, SD = .61), 74 NS fighters (mean articulation rate = 4.65, SD = .47), and 27 controls (mean= 5.23syl/s, SD = .70). Levene's test for equality of variances was significant ($F = 4.03$, $p < .02$). Results of the ANOVA indicated a significant difference in articulation rate among the three groups ($F = 13.98$, $p < .00$) with a medium effect size ($\omega^2 = .08$). Post hoc testing was done using the Games-Howell test because homogeneity of variance was not assumed. Post hoc testing indicated that there was no significant difference between WS and NS, there was a significant difference between WS and controls (mean difference = -.16, $p < .00$), and there was a significant difference between NS and controls (mean difference = -.57, $p < .00$). Figure 10 shows a comparison of distribution for articulation rate for WS, NS, and controls.

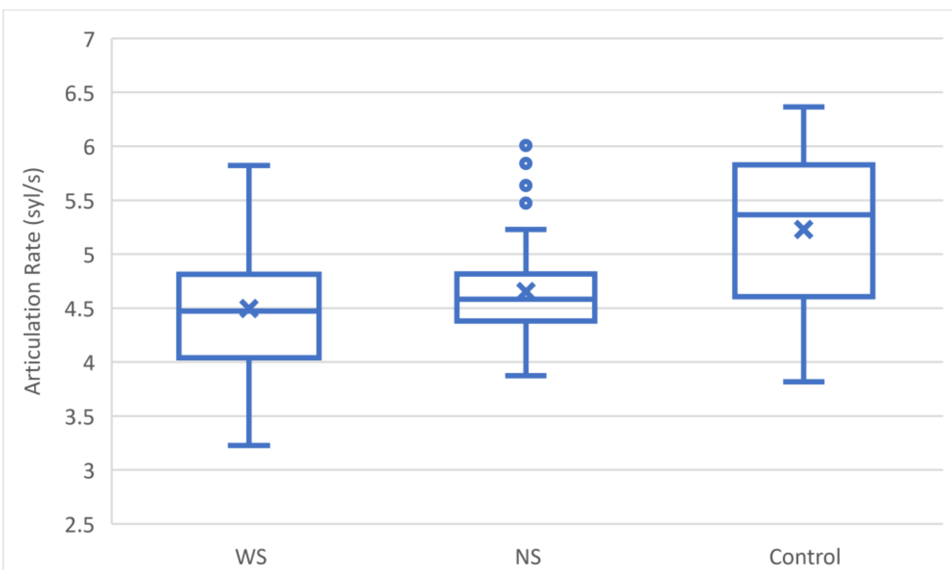

Figure 10: Articulation rate for fighters with speech symptoms (WS) and controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Syllable Duration

Because data for syllable duration was also normally distributed, an ANOVA was performed to analyze differences in syllable duration between WS fighters, NS fighters and controls. There were 28 WS fighters (mean duration = 226ms, SD = 31ms), 74 NS fighters (mean duration = 217ms, SD = 20ms), and 27 controls (mean duration = 194ms, SD = 28ms). Levene's test for equality of variances was significant ($F = 3.98$, $p < .02$). Results of the ANOVA indicated a significant difference in articulation rate among the three groups ($F = 12.17$, $p < .00$) with a large effect size ($\omega^2 = .15$). Post hoc testing was done using the Games-Howell test because homogeneity of variance was not assumed. Post hoc testing indicated that there was no significant difference between WS and NS, there was a significant difference between WS and controls (mean difference = 31.94, $p < .00$), and there was a significant difference between NS and controls (mean difference = 22.15, $p < .00$) Figure 11 shows a comparison of distribution for articulation rate for WS, NS, and controls.

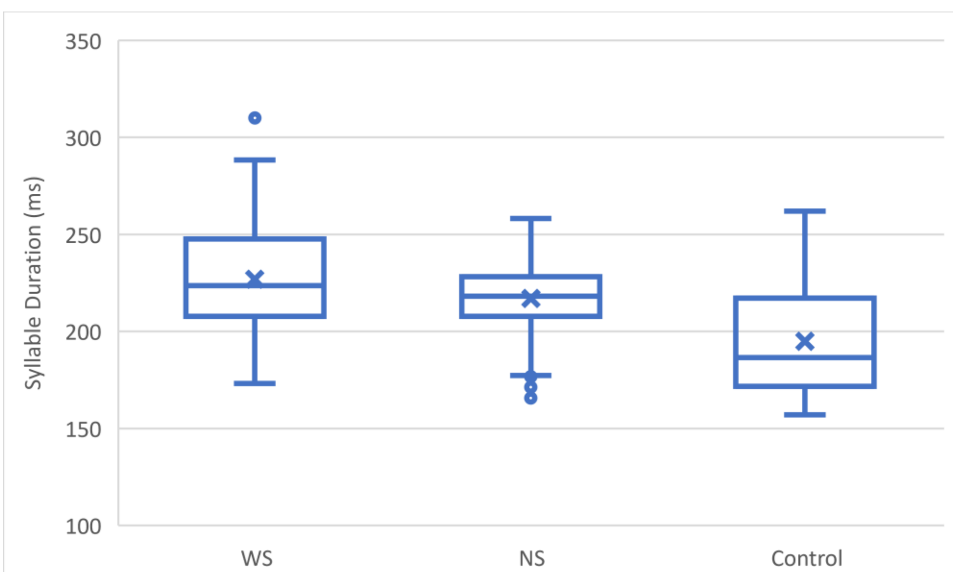

Figure 11: Syllable duration for fighters with speech symptoms (WS) and controls. X's are mean values, o's are outliers, box boundaries indicate 25^{th}, 50^{th}, and 75^{th} percentiles of data, and bars represent data extremes.

Number of pauses and disfluencies

The Kruskal-Wallis test was used to analyze differences in frequency for pauses and disfluencies because none of the variables were normally distributed except number of PG. An acceptable significance level of $p < .01$ was set in order to limit the type 1 error resulting from running multiple independent analyses. There were three variables that had significant findings: number of PAs, number of SLD, and number of ODs. For frequency of PAs, the $H(2) = 12.52$ ($p < .00$). The pair-wise comparisons showed that WS had significantly more atypical pauses than controls with a medium to large estimated effect size ($r = .47$). For frequency of SLDs, the $H(2) = 11.805$ ($p < .00$). The pairwise comparison showed that WS had significantly more SLDs than controls with a medium to large estimated effect size ($r = .44$). For frequency of ODs, the $H(2) = 19.32$ ($p < .00$). The pairwise comparison showed two significant comparisons; WS had more ODs than controls with a large estimated effect size ($r = .59$), and NS had more ODs than controls with a medium estimated effect size ($r = .30$). There was no significant difference among the three groups for number of grammatical pauses. Figure 12 shows a distribution of pauses and disfluencies for the three test groups.

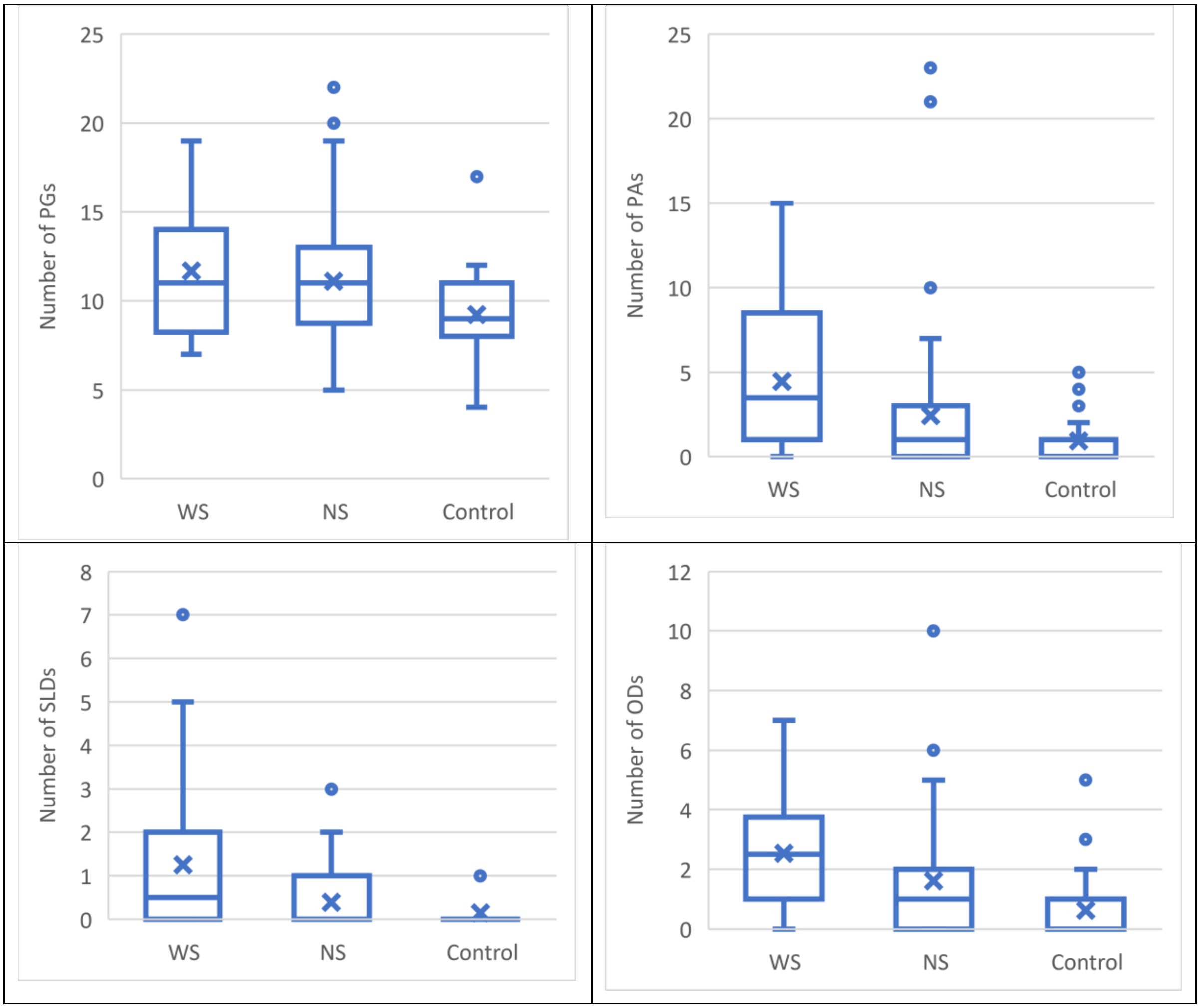

Figure 12: Comparisons in the number of pauses and disfluencies between WS, NS, and controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

Duration of pauses and disfluencies

None of the variables for duration of grammatical pauses, atypical pauses, SLDs and ODs were normally distributed or passed the assumption for homogeneity of variance. Therefore, the non-parametric Kruskal-Wallis test was used to compare durations of pauses and disfluencies among WS, NS, and controls. An acceptable significance level of $p < .01$ was set in order to limit the Type 1 error resulting from running multiple independent analyses.

There were no significant differences found during the analysis of durations of PGs, PAs, SLD, and ODs. For duration of PGs, $H(2) = 6.24$, $p < .04$). For duration of PAs, $H(2) = 4.31$, $p < .12$). For duration of SLDs $H(2) = 2.128$, $p < .35$. For duration of ODs $H(2) = .315$, $p < .86$. Figure 13 shows box plots of duration of the 4 types of interruptions in the forward flow of speech broken into groups for WS, NS, and controls.

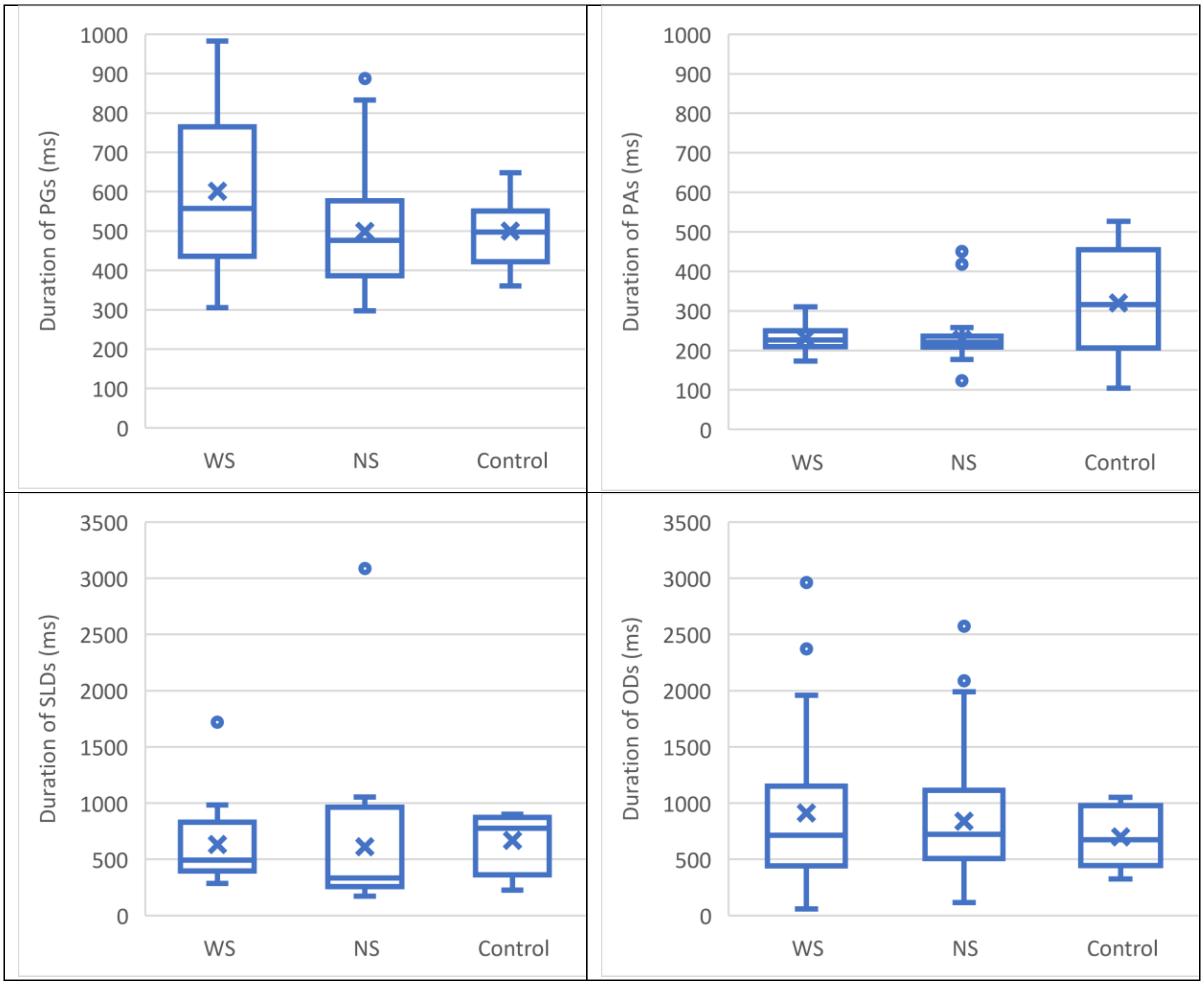

Figure 13: Box plots for differences in duration between WS, NS, and controls. X's are mean values, o's are outliers, box boundaries indicate 25th, 50th, and 75th percentiles of data, and bars represent data extremes.

DISCUSSION

This study is the first attempt to document acoustic characteristics of speech in a large cohort of professional fighters; 62 boxers and 40 mixed martial arts fighters who participated in the Professional Fighters Brain Health Study. Two previous reports in the literature which focused on speech characteristics were single case studies. McMicken et al. (2011) provided clinical descriptions of speech in a boxer diagnosed with ataxic dysarthria. Berisha et al. (2017) documented changes over time in speech rate, vowel space area, and vocal pitch in boxer Muhammad Ali, who was diagnosed with Parkinson disease. Because the clinical correlates of repeated head impacts in fighters are not completely understood, and autopsy remains the only definitive method for identifying chronic traumatic encephalopathy (Montenigro, Bernick, & Cantu, 2015), this study provides accurate measurements of several speech characteristics and preliminary findings for using speech features as biomarkers for neurogenic decline in fighters.

Research Question 1:

The focus of the first research question was to investigate if differences existed between the speech characteristics of fighters and control participants. Analysis of the data revealed that fighters, on average, produced slower articulatory movements and their speech contained more interruptions in the forward flow of speech than control participants. The mean articulation rate for fighters of 4.61 syl/s s was almost 12% slower for than controls (mean = 5.23 syl/s), and syllable duration was 25ms longer than controls. The effect size for articulation was large. 88% of fighters had slower articulation rates than the mean of the control group, and 49% had rates more than one standard deviation below the control mean. The finding of reduced speech rate is consistent with previously published research on boxers (e.g., Berisha et al., 2017 and many other historical reports) as well as the clinical presentation of several motor speech disorders associated with neurogenic damage. Decreased speech rate is also characteristic of several types of dysarthria, including hypokinetic dysarthria associated with basal ganglia dysfunction (Parkinsonism), ataxic dysarthria associated with cerebellar dysfunction, and unilateral upper motor neuron and spastic dysarthrias associated with unilateral or bilateral damage to the cerebral hemispheres (Duffy, 2013; Tykalova, 2016; McMicken, 2011).

The speech of fighters was also characterized by significantly more interruptions in the forward flow of speech than controls. Fighters' speech contained 1.2 times more grammatical pauses and 3.2 times more atypical pauses than controls. The effect size for grammatical pauses was small to medium: 66% of fighters had more than the mean number of pauses than controls, and 39% differed by more than one standard deviation from controls. The effect size for atypical pauses was small: 43% of fighters produced more than the control mean of one PA in the passage and 35% had more than one SD above the control mean. However, the number of PAs produced by some fighters is remarkable: the highest number of PAs produced by a control group member was five, but 18 fighters produced more than five ODs. Three fighters produced more than 20 PAs during the reading. The duration of pauses did not differ significantly between the two groups.

Although the effect size was small, stuttering-like disfluencies (blocks such as part-word repetitions and prolongations that are unusual in healthy speakers) were much more prevalent among fighters: only four control participants exhibited any SLDs and each of them produced only one SLD during the reading. In comparison, 33 fighters produced at least one SLD and 18 of them produced two or more up to a maximum of seven. Other disfluencies, such as interjections and phrase revisions that are observed in typical speakers, were also more numerous in the speech of fighters than controls. Only eight controls (30%) produced any ODs in the passage, whereas 72% of fighters had at least one OD, and 49% produced more than one OD. As with pause duration, disfluency durations did not differ significantly between fighters and controls. Detailed information regarding interruptions in the forward flow of speech has not been previously reported in the body of literature about RHI in fighters. However, the clinical presentations of motor speech disorders such as Parkinson's Disease and neurogenic stuttering include increased number of pauses, the presence of atypical pauses, and various types of disfluencies (Goberman, et al., 2010). Disfluencies may occur in association with damage to basal nuclei as in parkinsonism, or changes in the interaction between the anterior insula and Broca's area (Goberman et al, 2010; Huber et al., 2012; Alm, 2004; Ingham, 2001). Increased pause frequency and pausing in grammatically inappropriate locations may also be associated with deficits in respiratory control and laryngeal valving in various types of dysarthria and with motor planning deficits in apraxia of speech.

Research Question 2:

In the second research question, the aim was to compare the two types of fighters included in the PFBHS. Boxing and mixed martial arts are both combat sports; however, the rules and acceptable fight moves are very different. In boxing, the rules state that an opponent may not hit below the belt. Consequently, the majority of the hits in boxing are concentrated on the torso, neck, and head (Casson & Viano, 2019). Mixed martial arts allow all types of fighting including more floor-centered styles such as wrestling and jiujitsu; these include elements such as "holds" and "choke-outs" allowing for asphyxiation of an opponent.

Anoxia resulting from oxygen deprivation may affect the presentation of progressive neurogenic decline for the MMA population (Lim et al., 2019). Despite the differences in fighting style, measures of speech rate (articulation rate and syllable duration) were not significantly different between boxers and mixed martial artists. Additionally, neither frequency or duration of pauses and disfluencies was significantly different between the two groups with the exception of duration of grammatical pauses. Both boxers and mixed martial artists differed from controls in articulation rate, syllable duration, pause frequency, and frequency of disfluencies, but the two groups did not differ significantly from one another.

Research Question 3:

The third experimental question investigated the possible relationship between number of fights (a proxy for exposure to RHI) and speech symptoms. Previously published research introduced progressive neurogenic decline or CTE as a consequence of RHI (Baugh et al, 2012; Bernick et al, 2015; Forstl et al, 2010). It stands to reason that more frequent bouts or fighting events expose professional fighters to more RHI. In addition to this question, further correlational analysis was completed to assess possible relationships between speech symptoms and age as well as years of education completed. Finally, correlations were calculated for speech variables against each other to determine if they were inter-correlated.

Correlation between number of fights and speech variables revealed very few statistically significant results. There was a modest correlation between the number of fights and the number of both grammatical and atypical pauses: pause frequency tended to rise as number of fights increased. However, the other speech variables were not significantly correlated with the number of fights. It is important to note that the number of fights data available for this project only included the number of professional fights; the number of amateur fights, practice fights, and training fights cannot be determined from this data. Furthermore, the number of fights information did not include any measure of severity of the fight, such as how many hits were sustained, occurrence of knockouts, fight duration, or weight class of the fighters. Thus, number of fights may not be an adequate proxy for exposure to RHI in relation to speech changes.

Understandably, age was moderately correlated with the number of fights, accounting for 29% of variance, but did not correlate significantly with any other variables. Correlational analysis did not support the hypothesis that the speech variables measured in this study varied with increasing number of fights or with age. However, most of the population of fighters included in this study were aged 30 to 50, and it is possible that speech symptoms attributable to progressive neurogenic decline do not become apparent until later in life (McKee, 2011; Forstl et al, 2011). Linear analyses may not capture the relationship between number of fights and the speech variables measured in this study.

Years of education was weakly correlated with number of grammatical pauses (24%), number of other disfluencies (22%) as well as the duration of other disfluencies (31%). The relationship between years in school and the frequency and duration of pauses indicates the possibility that speech symptoms may be attributable in part to poorer literacy skills rather than to motor differences resulting from RHI. However, as fighters on average had 13 number of years of education, all of them completed a minimum of 10 years of school, and only six fighters did not complete high school, it is unlikely that literacy issues account for all of the speech differences between fighters and controls. In addition, years of education is an imperfect proxy for the complex constructs of literacy and reading fluency.

Inter-correlational analysis revealed that articulation rate, one of the major differences between fighters and controls, had a significant negative correlation with the number and duration of pauses (both grammatical and atypical), as well as the duration of other disfluencies. Articulation rate was calculated without the inclusion of pauses or disfluencies; therefore, it is interesting that the rate was related to the presence of interruptions in the forward flow of speech. The number of grammatical and atypical pauses also significantly correlated with their respective durations, meaning the more pauses a participant had, the longer they tended to last. There was also a modest tendency for interruptions in the forward flow of speech to co-occur in the speech of fighters. It is possible that the speech measures we chose may represent patterns of related behaviors rather than separate aspects of speech associated with neurogenic decline.

Additional Research Question:

Out of the total 102 fighters included in this study, the PFBHS identified a group of 28 fighters who presented with clinical speech symptoms according to the neurologist's exam on at least one of their visits. These symptoms included "slurred speech", "dysarthria", or "stuttering." In order to determine if the fighters with speech symptoms differed in articulation rate, number of pauses and disfluencies, or duration of pauses and disfluencies from those who did not present with speech symptoms, additional analyses were completed.

No significant differences in articulation rate and duration of syllables, pauses, and disfluencies for fighters with and without speech symptoms were noted. However, 61% of fighters with speech symptoms had articulation rates that were more than one SD below the control mean, whereas only 45% of fighters without speech symptoms had rates that slow. Fighters with speech symptoms had more atypical pauses and disfluencies (SLDs and ODs) than those without symptoms. Pause rates for 53% of fighters with speech symptoms were more than one SD above controls, but only 28% of non-symptomatic fighters had rates that high. For SLDs, 50% of fighters with symptoms had one or more SLDs, and only 26% of fighters without that label produced SLDs. ODs were also more prevalent in fighters with speech symptoms: 64% of WS fighters had more than one OD, but only 45% of NS fighters did. In their clinical examinations, PFBHS neurologists appear to be sensitive to substantial reductions in speech rate and to the presence of interruptions of the forward flow of speech in making determinations about speech deficits. However, subtle differences in speech rate and number of grammatical pauses may not be readily apparent during clinical evaluations.

Looking deeper into the data, we examined fighters whose speech characteristics differed substantially from controls. There were three fighters whose articulation rate was slower than the mean rate for controls by more than two standard deviations. All three were boxers who presented with clinical speech symptoms, as noted by the neurologist, and all three had a large number of fights (56, 57, and 85). There were 25 fighters who had more than 14 grammatical pauses which is two standard deviations above the mean for controls. Out of this group, 21 of them were boxers, with an average of 35 fights, and four were MMA fighters with an average of 25 fights. There were 33 fighters had substantially more atypical pauses than the mean for controls: 24 boxers with an average of 31 fights and nine MMA fighters with an average of 12 fights. Of the 28 fighters with high rates of SLDs compared to controls, 23 were boxers (average of 37 fights) and 5 were MMA fighters (average of 23 fights). Finally, 16 fighters had high numbers of ODs compared to controls: ten boxers (33 average fights) and 6 MMA fighters (9 average fights). While these findings are not definitive, they suggest that fighters who presented with the slowest rates of speech and highest number of interruptions in the forward flow of speech are boxers who participated in more fights on average (mean = 31) than the fighters group as a whole (mean = 23). Although the correlation analyses did not reveal strong linear correlations between number of fights (as a proxy for exposure to RHI) and any of the speech variables, further analysis of fighters with high exposure to head injury is warranted.

Summary

The primary purpose of this project was to accurately measure and describe some of the speech characteristics – articulation rate and number and durations of interruptions in the forward flow of speech – of professional fighters involved in the PFBHS. In addition, we compared those speech characteristics of fighters to a group of healthy age-matched controls to investigate if speech characteristics could serve as a biomarker for RHI. The most robust finding of this study is the large difference in number of syllables spoken per second for fighters compared to controls. In addition, fighters produced more interruptions in the forward flow of speech in the form of grammatical pauses, pauses in atypical locations, and both stuttering-like and other disfluencies. Reduced speech rate and interruptions in the forward flow of speech may be indicative of neurological symptoms and can impact the intelligibility and naturalness of speech. Relatively small reductions in speech rate compared to typical adult speakers and subtle interruptions in the forward flow of speech may be difficult for listeners, including neurologists, to make during clinical examinations. Therefore, acoustic measures of speech rate, pausing, and disfluency have the potential to improve early identification of speech changes in professional fighters.

Limitations and Future Directions

There were a number of limitations in this project, some of which could be addressed in future research. The recordings obtained from the PFBHS varied in sound quality and amount of noise in the signal. For some of passages, determining syllable boundaries was challenging. The sound quality and noise may affect measurement of acoustic correlates of voice quality, pitch, loudness, intonation, and articulatory accuracy in future studies. The control group used for this project, drawn from a previous study, and collected in a different setting, was not optimal for statistical comparison. Although matched by age and gender, there was no additional information about controls. The control participants self-reported that they had no problems with speech or language, however, they were not asked about any relevant history of concussion or head trauma. In addition, the recordings were made in a different sound environment and may have involved different instructions. However, it is unlikely that the recording differences greatly impacted the comparisons of the measures in this study.

The speech samples analyzed in this project were passages read aloud. The act of reading is fundamentally different from conversational speech and may not accurately reflect a person's true speech characteristics. Some aspects of dysarthria and apraxia of speech are difficult to detect in connected speech, particularly in read speech (Brown & Docherty, 1995). Articulation rate and fluency in reading can be affected by literacy and comfort with reading aloud in front of another person as well as cognitive ability. Reading aloud is a task that involves both speech production and language. It is possible that some of the differences in speech measures we discovered in this study reflect cognitive or language deficits in addition to or even more significantly than speech. Diadochokinetic rate tasks (rapid repetition of syllables) may be more resistant to literacy, language, and cognitive issues associated with reading tasks and may be more effective in determining the type of motor speech disorder present, leading to a better understanding of neurologic correlates of RHI in fighters.

As a first attempt to assess the acoustic signals of speech produced by fighters, we limited our focus to a small group of variables that were relatively straightforward to measure in noisy recordings. However, there are many more aspects of speech involved in motor speech disorders including imprecise articulation of consonants and vowels, changes in phonatory quality (e.g., hoarseness, breathiness, and strained voice), hypernasality associated with velopharyngeal dysfunction, and deficits in prosodic adequacy (impairment of the rhythmic and intonational features of speech). In listening to the speech samples, we observed that some participants had harsh, hoarse, breathy, or strangled voice quality. A few had hypernasal resonance (suggesting velopharyngeal insufficiency), and several participants had articulation distortions. Several participants evidenced reductions in speech intelligibility – their speech was somewhat difficult to understand despite our familiarity with the passage. Additional perceptual and acoustic measures, including measures of articulatory accuracy, voice quality, prosodic adequacy, and resonance balance, should be analyzed in future projects in order to obtain a complete speech profile for fighters. Further studies should also aim to correlate speech findings with imaging data in order to support our understanding of the clinico-pathologic nature of RHI. Because neurogenic decline resulting from RHI is reported to be progressive, investigators should also consider tracking the speech characteristics of individual fighters over subsequent visits to investigate if their speech symptoms decline or remain constant over time. Another direction for future projects would be to investigate the same set of speech variables presented in this study in conversational speech (as opposed to read speech) to eliminate issues with literacy or to use diadochokinetic rates to examine the speed, accuracy, and coordination of speech production without linguistic confounds.

There are significant clinical implications from this study. Neurologists who assessed these participants identified only 30% of the participants with remarkable speech differences. However, our findings illustrate that even those fighters whose speech was not flagged as impaired differed significantly in speech rate and fluency from the speech of controls. This illuminates the need for more thorough training for medical professionals who will be performing clinical assessment for RHI. In addition, our findings show the need for more sensitive acoustic tests for speech changes (such as diadochokinetic rate tasks) associated with neurogenic damage in fighters. Because speech is highly sensitive to neurologic disturbance, speech tasks have the potential for detecting subtle changes in motor behavior that will allow for the early diagnosis of neurologic injury in living athletes to prevent later life-altering deficits.

APPENDICES

Appendix A: Complete list of Fighter participants with demographic information.

Participant ID	Visit Used	Fighter Type	Age	WS or NS	# of Fights
32	6	Boxers	41	NS	37
46	3	Boxers	41	NS	35
68	1	Boxers	39	WS	13
81	1	MMA	40	NS	0
83	1	Boxers	33	WS	33
88	1	MMA	33	NS	0
89	1	Boxers	34	WS	6
101	1	MMA	35	WS	17
107	1	MMA	30	NS	16
115	1	MMA	38	NS	14
139	2	Boxers	45	NS	14
144	7	MMA	42	NS	78
145	5	Boxers	35	NS	18
151	1	Boxers	35	NS	15
175	1	Boxers	26	WS	0
185	4	MMA	35	NS	18
186	1	MMA	26	NS	0
212	3	MMA	40	NS	12
225	1	MMA	30	WS	15
249	2	Boxers	46	NS	63
265	1	MMA	24	NS	4
286	1	Boxers	24	NS	5
303	1	MMA	26	NS	6
309	1	MMA	26	NS	1
326	2	MMA	24	NS	2
331	1	Boxers	40	WS	10
337	1	MMA	27	NS	0
346	1	Boxers	45	WS	56
353	1	Boxers	24	NS	0
360	6	MMA	24	NS	1
365	6	Boxers	66	NS	47
371	1	MMA	35	NS	0
372	1	MMA	27	NS	0
374	1	Boxers	61	WS	16
388	1	MMA	24	NS	7
407	2	MMA	33	NS	10
419	1	Boxers	45	NS	37

421	1	MMA	24	NS	0
443	5	MMA	37	NS	3
451	1	Boxers	66	NS	64
452	1	Boxers	57	NS	34
460	2	Boxers	35	NS	0
466	2	Boxers	61	NS	1
478	1	MMA	36	NS	29
496	1	Boxers	44	NS	3
547	4	Boxers	24	NS	19
563	2	Boxers	56	WS	65
583	1	Boxers	50	WS	59
585	1	Boxers	24	NS	5
604	1	Boxers	43	NS	34
626	1	Boxers	42	WS	57
635	1	MMA	39	NS	5
652	1	Boxers	36	WS	40
696	1	Boxers	27	WS	14
704	1	Boxers	35	WS	24
713	1	Boxers	53	NS	51
729	3	MMA	33	NS	17
771	1	Boxers	46	WS	59
796	1	Boxers	48	WS	85
814	4	MMA	24	WS	9
826	2	Boxers	39	NS	7
834	3	MMA	29	NS	14
845	4	MMA	29	NS	6
850	1	Boxers	52	WS	27
864	1	Boxers	45	NS	6
881	3	Boxers	44	NS	25
889	1	Boxers	37	WS	51
919	1	Boxers	46	WS	41
924	3	Boxers	47	WS	15
960	1	MMA	34	NS	11
986	1	Boxers	53	WS	6
988	1	MMA	36	NS	50
1,011	1	Boxers	33	NS	16
1,030	1	Boxers	39	NS	41
1,054	1	Boxers	56	NS	28
1,059	1	MMA	33	NS	32
1,064	1	MMA	47	NS	17
1,120	1	Boxers	45	NS	20

1,128	1	Boxers	39	NS	2
1,146	1	Boxers	48	WS	44
1,147	1	Boxers	45	WS	56
1,204	2	MMA	37	NS	29
1,214	1	Boxers	43	WS	54
1,244	2	Boxers	32	NS	10
1,250	1	Boxers	28	WS	13
1,276	1	Boxers	33	NS	19
1,279	1	Boxers	51	WS	13
1,297	1	Boxers	53	NS	21
1,300	1	MMA	38	NS	42
1,352	1	MMA	36	NS	23
1,367	1	MMA	30	NS	16
1,417	1	MMA	44	NS	26
1,474	1	Boxers	47	NS	32
1,477	1	Boxers	46	NS	52
1,480	1	Boxers	54	NS	26
2,165,669	1	MMA	39	NS	36
21,611,149	1	Boxers	46	NS	38
21,611,372	2	MMA	37	NS	1
21,611,456	1	Boxers	69	NS	40
21,611,586	2	Boxers	49	NS	0
21,611,697	1	Boxers	47	NS	17
21,611,782	1	MMA	44	NS	64

Appendix B: Complete list of Control participants with available demographic.

Participant ID	Age
1	26
2	23
3	30
4	40
5	39
6	33
7	34
8	26
9	38
10	29
11	36
13	24
14	21
16	20
17	34
18	65
19	78
20	59
21	46
22	42
23	57
24	50
25	46
26	58
27	76
28	52
29	58

Appendix C: Rainbow Passage marked with grammatical pauses.

When the sunlight PAUSE strikes raindrops PAUSE in the air PAUSE they act like a prism PAUSE and form a rainbow. PAUSE

The rainbow PAUSE is a division PAUSE of white light PAUSE into many beautiful colors. PAUSE

These take the shape PAUSE of a long round arch PAUSE with its path high above PAUSE and its two ends PAUSE apparently beyond the horizon. PAUSE

There is PAUSE according to legend PAUSE a boiling pot of gold PAUSE at one end. PAUSE

People look PAUSE but no one ever finds it. PAUSE

When a man PAUSE looks for something PAUSE beyond his reach PAUSE his friends say PAUSE he is looking for the pot of gold PAUSE at the end of the rainbow.

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